GENERAL SCIENCE FOR YOU

A Textbook for Secondary Schools

VOLUME ONE

Rs. 3.00

Acknowledgements

Foreword

IN THE second half of the twentieth century, the importance of science and technology to every nation does not need to be argued It is evident to the most casual observer The explosive expansion of scientific knowledge that began in the first half of the century, is a potential source of fundamental improvement in a nation's economy, capable of bringing to every citizen more food and water, better clothing and shelter, greater opportunities for education and wage-earning and, in general, a healthier, safer and more rewarding life But if a nation is to be able to exploit modern science and technology, it must have men and women competent to do fundamental scientific research, and men and women capable of translating the resulting knowledge into means for improvement of the national economy

What is true of all nations is true in a special degree of developing societies such as India's If the recognition of one truth in education in the twentieth century is more valuable than any other, it is that education is the most potent instrument for change anywhere India, the developing society *par excellence,* is at the stage of pulling herself up by the boot-straps out of the rut of a traditional society, to move into the orbit of modernity that is a pre-condition of national survival Unless she can effect this change swiftly and effectively, she cannot survive.

Improvement in the total standard of science and mathematics is a continuous process that demands three integrated steps, and the process begins necessarily at school level It moves as follows ·

i) Development of a curriculum that includes modern concepts and understandings of the subject-fields and a rigorous analytic study of fundamentals

ii) Preparation of textbooks based on the new curriculum; teachers' guides and manuals and other instructional materials, design of experimental kits and apparatus.

iii) Training teachers and equipping them with the necessary competence to introduce the new curriculum into the classroom

In all progressive countries, the preparation of textbooks and instructional materials has been a cooperative effort in which university professors and top-flight scientists have worked closely with top-flight science teachers. In India, it is distressingly true that school and university teachers seem not to have met at the professional level, and that the interchange of experience and knowledge between these levels of educational learning and practice has, therefore, hardly existed The recognition that this gap must be bridged may have come to us late, but it has come, and this is a matter for rejoicing

The National Council of Educational Research and Training, in cooperation with university professors and other eminent scientists in the country, has undertaken a comprehensive programme to improve science education at all stages of school education.

The three most important aspects of the programme are the in-service training of science teachers on a continuing basis at summer institutes, the development of a new curriculum in science and mathematics, and the preparation of standard textbooks. The present volume of *General Science for You* is the result of the work done by a group of eminent scientists and educators under the National Council's Science Education Programme.

As a first step towards the preparation of the book, the National Council set up a panel of experts to hammer out a comprehensive curriculum in general science. The main concern of the Panel was how to present general science to students as a unified body of knowledge that could lead to a surer understanding of the nature of the physical world and life, development of a scientific attitude and application of science to everyday life. To this end, the Panel produced a large volume of materials on chosen topics, discussed them at a series of meetings, modified them and re-wrote them to suit teaching at school level. After the work of the Panel was over, to speed up the process of bringing out the textbooks, the National Council set up an Editorial Board with Dr. B. D. Nag Chaudhuri as Chief Editor and Dr R. C. Paul and Dr S. Ramaseshan as Editors.

This general science textbook, as finalized by the Editorial Board, is for the sake of convenience in two volumes. The present volume deals mainly with the physical world. The second volume, that will also be published shortly, will be mainly concerned with living things. The need to have two volumes of a convenient size has dictated the decision, that is not based primarily on specialized classification.

Although the modern trend all over the world is to teach science as separate subjects, i e, as physics, chemistry, biology and mathematics, and in depth, there is still a large body of educational opinion that is in favour of general science. Today, in a number of our schools, science is still being taught as general science, and the present position will continue till a decisive change is made to teach the subjects separately. The textbook of general science now published by the National Council is designed to meet our *present* need, but a separate programme is under way to produce standard textbooks in physics, chemistry, biology and mathematics as separate subjects.

The National Council is grateful to the General Science Panel and to the Editorial Board presided over by Dr B D Nag Chaudhuri for the collective precision and thoroughness with which the textbook has been completed. We would welcome comments and suggestions from scientists, teachers and other educationists, and consider them carefully in bringing out a revised edition of the textbook.

L S CHANDRAKANT

NEW DELHI

Joint Director

May 1967

National Council of Educational Research and Training

Contents

Matter and Energy

I. Crystals

Nature provides us with many beautiful examples of crystals They can be recognized by their fascinating geometrical shapes Our forefathers considered crystals as beautiful gifts of nature and called them *sphatika* They have eloquently described the beauty of the crystals found in nature The ancient Greeks had observed that the crystals of quartz usually occur in forms having characteristic shapes bound by flat faces The transparency of quartz, the Greeks thought, was due to the freezing of water under intense cold Hence they gave it the name *krustallos* which means 'clear ice' Later, the English modification of the word, crystal, came to denote any solid substance showing such a well-defined shape
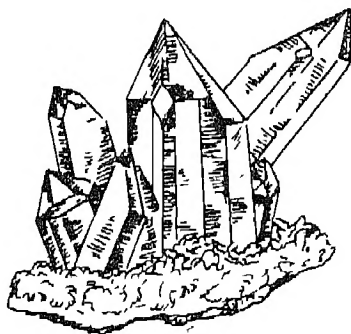
FIG 1 1a *Quartz crystals*

If we examine the solid substances around us, we can divide them into those which show beautiful crystal forms and those which do not For example, sugar and salt ordinarily look like fine powders, but you must also have seen crystals of sugar *(misri)* or crystals of salt Even when sugar and salt are in the form of a fine powder one can examine them through the magnifying lens or microscope Looking at them thus you will notice that the tiny grains of salt or sugar still show the characteristic plane faces, sharp edges and corners that distinguish crystals We can extend our observation to many of the things around us to find out whether they are crystalline or not What do we mean by the word *crystalline?* We recognize a crystal quite easily when we see the edges and the flat faces Therefore, let us for the present define crystals as solid bodies which are bounded by plane faces, straight edges and sharp
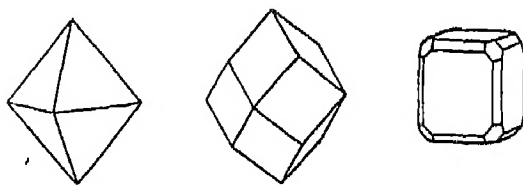
FIG 1 1b *Crystals plane faces, straight edges, sharp corners*

corners Very often we make the mistake of calling glass a crystal because of the beautiful shapes it is made to display These shapes are made by man Glass, when it breaks, does not display plane faces or straight edges or corners Crystals of sugar or salt, however, continue to show these beautiful faces, when broken We

may say that one of the characteristic features of a crystal is that the beautiful geometrical forms persist even when they are broken

Crystals may be made by the slow evaporation of solution The process by which a crystal is formed is called 'crystallization' Crystallization can also occur when a liquid is cooled slowly The solidified crystal takes the shape of the vessel When it is broken it displays plane faces We shall later see that what defines a crystal is the beautiful geometrical arrangement of the atoms

Non-crystalline substances are called *amorphous* or *glassy* Pitch or tar is an amorphous substance

Crystals are bounded by a number of surfaces which are usually perfectly flat, but in some rare cases they are curved as in certain specimens of diamond These plane surfaces are called the faces of the crystal. In a single crystal the faces may be classified into two kinds . *like* and

FIG 1 2c   *Galena crystal*

and have both like and unlike faces The intersection of any two adjacent faces is called the edge of a crystal. If you examine the crystal carefully you can notice the regularity of the position of the like faces, edges, etc. This regularity often constitutes the symmetry of the crystal. The symmetry varies with different types of crystals and is employed to classify crystals into various groups One usually uses the following three criteria of symmetry ·

   1 Plane of symmetry
   2. Axis of symmetry
   3 Centre of symmetry

FIG. 1 2a   *Diamond 'brilliant' cut*
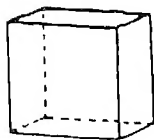
FIG. 1 2b   *Sodium chloride crystal*

unlike You would see from the diagram of the common salt crystal, which is a simple cube, that all the faces are alike Another simple crystal having all the faces as triangles is the simple octahedron diamond crystal which takes the form of an octahedron Galena (PbS) crystals combine a cube with an octahedron

FIG 1 3   *Plane of symmetry, axis of symmetry and centre of symmetry*

AXIS OF SYMMETRY

CENTRE OF SYMMETRY

PLANE OF SYMMETRY

PLANE OF SYMMETRY

There are many examples around you of crystalline substances We have already mentioned sugar and salt. The crystals of sugar and salt can be made quite easily from a saturated solution of the substance in water Copper sulphate is another substance which would give beautiful crystals with just a little effort. You can buy

this substance in the market Dissolve it in water to form a very strong solution, then filter the solution and keep it in an open glass The water will evaporate and leave beautiful crystals in the glass Remember that copper sulphate is poisonous

Nature is very prolific in the production of crystals. Most of these crystals were formed thousands of years ago, very rarely do we come across the extremely beautiful, single crystals
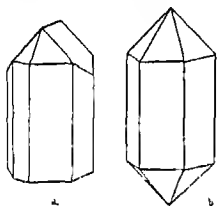
FIG 1 4
a   *Topaz*   b   *Quartz*

However, single crystals of quartz, diamond and mica are well known You will notice that the crystals of mica look entirely different, being extremely flat. Other single crystals also occur in nature in the form of precious stones such as ruby and sapphire However, most substances in nature occur as minute crystals mixed with other kinds of crystals and substances

Take the example of a powdered mineral. Look at this powdered substance through the microscope or magnifying lens You will notice small crystals of similar shape and colour The mineralogists and geologists recognize these crystals and detect these substances by looking at them through a microscope

If you have made copper sulphate crystals or sodium chloride crystals, inspect them carefully Notice the faces, edges and corners of the crystal Look at the crystals of the same substance made by one of your friends and count the faces, edges and corners See whether they are the same. You would notice that the crystals of the same substance, e g , copper sulphate or aluminium,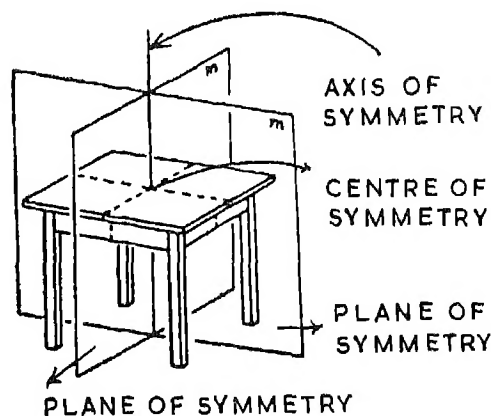 look alike except for their sizes. They may be smaller or larger, but they have the same corners, edges and faces. Make

a small goniometer with the protractor, as shown below Measure the angles between the faces of your crystal and compare the results with those of your friends
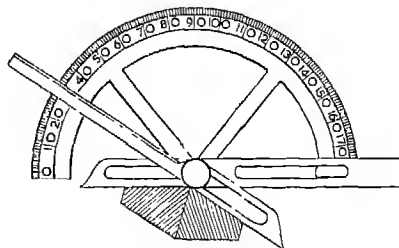
FIG. 1 5   *Goniometer*

Most crystals dissolve in a suitable liquid For example, sugar, salt and copper sulphate dissolve in water Sulphur *(gandhak)* does not dissolve in water, but it does dissolve in another liquid, viz , carbon disulphide (CS_2). You can crystallize sulphur from a solution of sulphur in carbon disulphide. We have only discussed the simple crystals The shapes of crystals are many For example, common salt is a cubic crystal, mica, on the other hand, forms sheet-like crystals Sulphur forms crystals of long needles (monoclinic) as well as rhombic crystals In the human body and in other living

FIG 1 6   *Mica crystal*
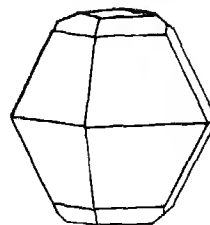
FIG 1 7   *Sulphur crystal*

things there are many examples of crystals Our hair and bones are crystalline. The calcium

phosphate in the bones forms crystals which are similar to the crystals of apatite in nature However, the crystalline nature of biological substances like bones or hair is quite complicated and we shall not discuss them here

The crystals of metals, for example, aluminium or zinc, are not clearly apparent One simple method of showing the crystalline nature of a sheet of aluminium is to treat the surface of the sheet with acid The acid will corrode the various faces of the aluminium crystals at a different rate. If you now observe the aluminium sheet under a microscope in reflected light, crystals can be seen If you heat the aluminium sheet, and cool it slowly, the crystals will be larger and quite easy to see A similar method can be used to reveal the crystalline structures of many other metals

The shape of the bricks we ordinarily use for building houses is rectangular The bricks that go to make a crystal are usually of the same shape as the crystal itself From such bricks or sub-units, crystals are built so that their faces are either plane or stepped In fact, you may have noticed that if bricks are stacked in such a way that the amount of empty space between them is reduced as much as possible, the stack is more stable than if the bricks were haphazardly jumbled together Even the smallest unit of the crystal has a certain shape The best stacking arrangement leaves the least amount of empty space in between and will depend on the shape of the unit brick.

Atoms combine to form molecules The number and the various species of atoms that form a particular type of molecule determine the shape and size of the molecule The atoms within the molecule have certain specific relationships with each other The atoms are bound together by chemical forces called valency bonds A few molecules arrange themselves to form the elementary building block of a crystal This elementary block is called the unit cell These units are arranged in patterns and extend in all directions up to the boundary of the crystal. The smallest of these equivalent
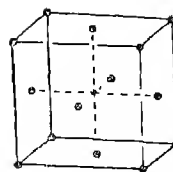
FIG 1 8　　Unit cell

units is called the unit cell of the crystal lattice The crystal, however, is finite It ends somewhere near the boundary or surface, and the surface of the solid crystal matter differs from its interior.

The arrangement of cells forming a crystal is rarely perfect Sometimes stray atoms are found in the lattice In some places the lattice may not form but there may be a small gap where atoms have been left out At these points the completely symmetrical nature of the crystal is disturbed, the interatomic forces are slightly unbalanced and the lattices undergo slight changes or distortion to allow for this. Often, in natural crystals these extra atoms may be atoms of different elements or impurity atoms The valency of the impurity atoms need not necessarily be the same as that of the atoms of the crystal located in the same position. For example, the inclusion of a calcium atom in a sodium chloride crystal in the place of a sodium atom gives rise to an impurity of an element with a valency of 2 instead of 1 There are other impurities due to the size of the impurity atom being different from the size of the original atom in the crystal; for example, when sodium is replaced by rubidium. The various kinds of impurities have been studied and classified by scientists in accordance with the effects they produce For example, a slight amount of chromium in aluminium oxide crystals gives rubies their characteristically beautiful red colour These impurities in crystals have sometimes been found to give very useful properties to crystals In other cases they produce effects which are not useful

II. Molecules and bonds

Molecules are the building bricks of all matter

and are composed of atoms of various elements The molecule of one substance or compound contains a certain fixed number of atoms These atoms may be of different types (or of different elements) or of the same type (or element) For example, the hydrogen molecule is composed of 2 atoms of the element hydrogen. Similarly, 2 atoms of oxygen form 1 molecule of oxygen Another type of molecule made up of oxygen atoms is called 'ozone' and is composed of 3 atoms of oxygen Other molecules, such as those of common salt (NaCl), consist of two varieties of atoms one atom of sodium element (Na) and the other of chlorine element (Cl) A water molecule (H_2O) is composed of 2 hydrogen atoms combined with 1
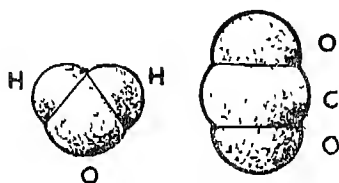
FIG 1 9   *Water and carbon dioxide molecules*

atom of oxygen These are examples of simple molecules There are, however, molecules of much larger size and complexity in nature For example, a molecule of sugar contains 12 atoms of the element carbon, 22 atoms of the element hydrogen and 11 atoms of oxygen The structure of the sugar molecule is shown in Figure 1 10
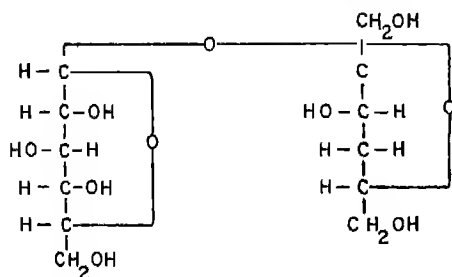
FIG 1 10   *Structure of the sugar molecule*

The sugar molecule is far more complicated than the hydrogen or water or common salt molecule An example of a really complex

molecule is that of haemoglobin These molecules which contain thousands of atoms occur in the blood and give blood its red colour. Each molecule of haemoglobin contains four atoms of iron, besides many hundreds of atoms of hydrogen, oxygen, carbon and nitrogen.

There are attractive forces which keep the atoms attached to each other to form molecules These attractive forces between atoms have been investigated by chemists and physicists and have been classified. The number of attractive bonds that an atom has are called its valency bonds For example, we say that oxygen has twice the number of valency bonds that hydrogen has

These valency bonds are fairly easy to examine One of the simple rules to be kept in mind is that atoms of the same kind generally have the same valency For example, all hydrogen atoms have a valency of 1 Similar is the case with chlorine and sodium Carbon atoms have the valency 4 To this rule there are a few exceptions which need not be discussed here

The valency of the hydrogen atom is said to be unity This means it is attached to molecules with 1 valency bond Oxygen, however, has 2 valency bonds because 2 atoms of hydrogen combine with 1 atom of oxygen Similarly, carbon is said to have a valency of 4 because 4 hydrogen atoms combine with 1
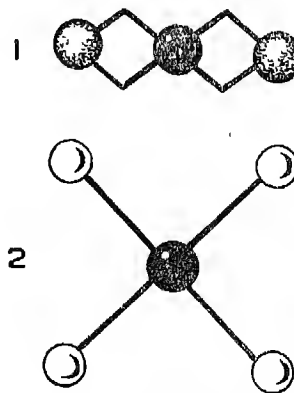
FIG 1 11   *Models of molecules*
  1   *Carbon dioxide*
  2. *Methane*

carbon atom (Methane, CH₄, is one of the main constituents of coal gas which is used for cooking in a large number of homes in many cities) The idea of the valency of atoms of a particular element enables us to predict how certain atoms will combine to form molecules Atoms of a particular element have a particular valency which it exhibits ordinarily. There are some elements whose atoms exhibit more than one kind of valency Copper, for example, forms CuCl and CuCl₂ Thus it exhibits the valencies 1 and 2 Since we know that the valency of chlorine is 1 and the valency of carbon is 4, we can expect 4 atoms of chlorine to combine with 1 atom of carbon This is exactly what happens The compound carbon tetrachloride (CCl₄) is well known and is often used in the laboratory as a solvent because of its ability to dissolve oils and greases of many varieties It is also used for cleaning the grease off machines and for the dry-cleaning of clothes.

The nature of the force which gives rise to a valency bond has been investigated by physicists and chemists The valency bond forces are not very simple There are many kinds of forces between atoms which give rise to valency Of these, two are quite important The first is called the ionic or polar bond The second is called the covalent bond

An example of the ionic bond between atoms is the bond between the sodium and chlorine atoms in sodium chloride (common salt). The force of the ionic bond is basically electrostatic in nature and really represents the electrostatic attractive force between sodium and chlorine. The sodium atom contains an outer electron which is loosely bound and can be lost quite easily On losing an electron the sodium atom becomes positively charged with a single unit of positive electricity Chlorine, on the other hand, has a vacant place for electrons in its outermost ring of 7 electrons and can therefore capture an extra electron very easily [1] Chlorine,

on capturing the extra electron, becomes negatively charged with a unit negative charge The positively charged sodium atom and the negatively charged chlorine atom attract each other because of the electrical forces between them (See Figure 1 12) In some cases more than one electron can be transferred to form an ionic bond Usually if a chemical compound with an ionic bond is dissolved in water and a small electric voltage or potential is applied between the two electrodes immersed in the solution, the positively and negatively charged atoms of the ionic compound in the solution move under the influence of the electric field in opposite directions towards the electrodes and carry an electric current from one electrode to the other. The electrical resistance of a solution of an ionic compound like common salt (sodium chloride) is quite small because of the ability of the charged sodium and chlorine atoms to carry electric current easily The charged sodium and chlorine atoms in a solution are called sodium and chlorine ions, respectively

The covalent bond on the other hand arises from a more complex force which is very different in character to the ionic bond The covalent bond is due to the ability of individual atoms to share electrons with the neighbouring atoms For example, 2 electrons of the 2 hydrogen atoms can be shared by both the atoms in the hydrogen molecule (H₂) One can think of each hydrogen atom possessing two electrons for a part of the time, no electron for another part of the time and only one electron for the rest of the time. Or, a more accurate picture would be to think of the electrons as forming clouds of charge around the two positively charged nuclei of the hydrogen atoms (See Figure 1.13) The calculation of the force of such a bond is more complicated.

A molecule composed of atoms bound by covalent bonds, when dissolved in water, does not show any lowering of resistance as in the case of a dissolved ionic compound Since the electrons are shared between 2 atoms in a covalent bond, the 2 atoms do not separate
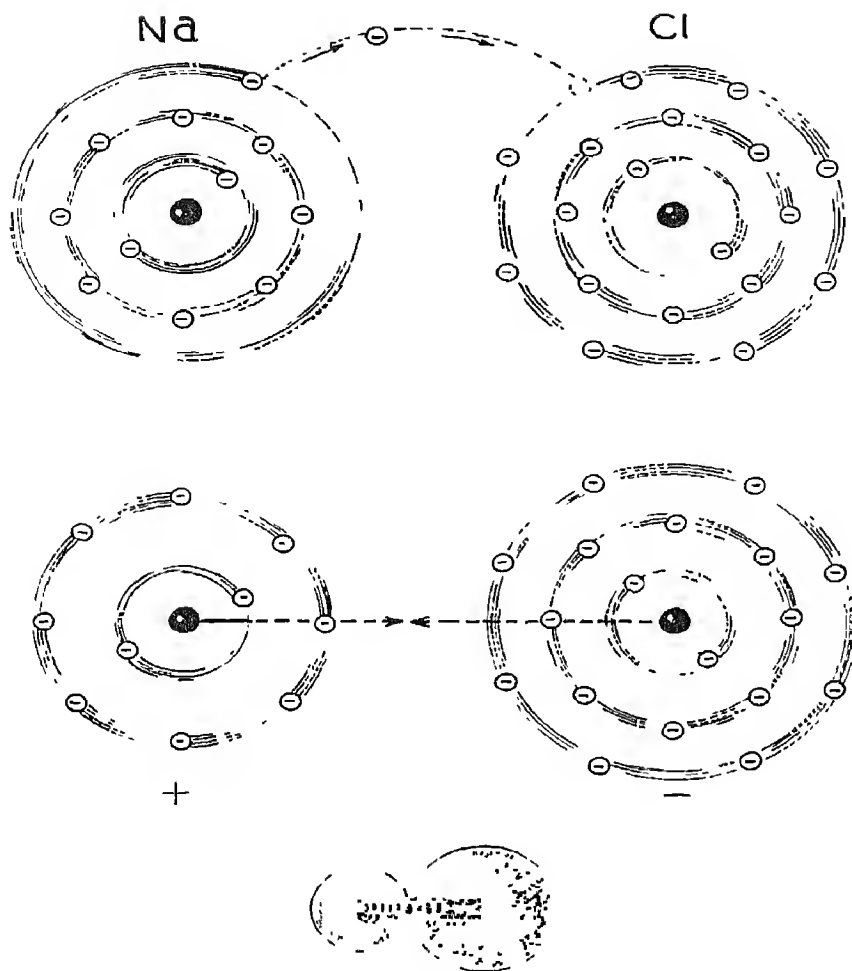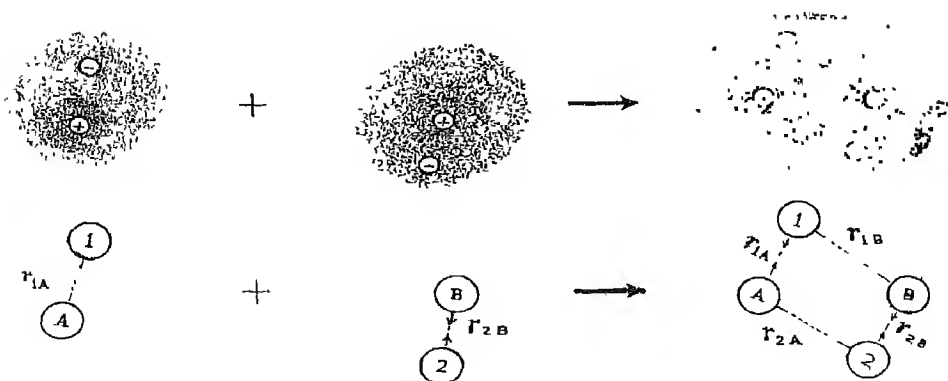
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[1] See Section IV on page 12.

FIG. 1.12 *The ionic bond in sodium chloride*

FIG. 1.13 *How a molecule of hydrogen (H_2) is formed*

in solution and so no individual charged atoms are formed which can carry electric currents. You can carry out an experiment by measuring the resistance of water, then measuring it after dissolving some sugar, which is a covalent compound, and then measuring it after dissolving salt in water, and finally tabulating the results.

As mentioned earlier the atoms of some elements such as copper and iron show more than one valency. This is mainly due to the fact that the number of electrons in the outermost ring or orbit of these atoms can vary. Copper exhibits a valency of either 1 or 2. Iron exhibits a valency of either 2 or 3. There are certain gases, called noble gases, which do not exhibit any valency. They are supposed to have a valency of zero. This means that they do not combine with the atoms of any element. For example, helium, neon, krypton, xenon and radon have zero valency.[2]

The atoms of the different chemical elements are not all of one size. When atoms of different elements combine to form molecules, the strength of the forces between them and their different sizes cause them to be arranged in a particular way in the molecule. This essentially determines the shape of the molecule. For example, the nitrogen atom is much larger than the hydrogen atom. Since nitrogen is trivalent, 3 hydrogen atoms combine with nitrogen to form ammonia (NH_3) These three hydrogen atoms, being equally attracted by nitrogen, arrange themselves symmetrically in three directions (Figure 1 14), equally distant from
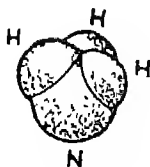
FIG 1 14   *Ammonia molecule*

[2] Very recently, however, it has been found that, under very special circumstances, krypton and xenon, although they are supposed to have zero valency, can combine to form molecules with fluorine, chlorine, etc

the nitrogen atom. Similarly, methane (CH_4) molecules contain carbon with a valency of 4. One can immediately suggest that these 4 atoms of hydrogen would be distributed in a space exactly symmetrical with respect to each other. This suggests how a CH_4 molecule may look. If you join the four corners, which represent the position of the hydrogen atoms, it would form a regular tetrahedron with carbon at the centre (See Figure 1 11)

If you take a crystal of solid methane, you will find the tetrahedral structure of solid CH_4, which really reflects the packing of the tetrahedral molecules of CH_4 close to each other so as to occupy the least amount of space. The shape of a crystal, therefore, reflects the effect of the molecules being stacked together compactly to form larger assemblies. Physicists study the structure of crystals by using X-ray, optical and various other methods. The importance of determining the structure of crystals is that it enables the scientists to form an idea as to how molecules are arranged or stacked in a crystal. Many of the properties of crystals, such as hardness, depend on the stacking of molecules.

III. Metals, non-metals and semi-conductors

There are many kinds of elements which are solid in their pure form at the ordinary room temperature. If we examine their electrical properties, especially the ability to pass electric current, we can classify all the solid elements in their pure form in three broad groups

The first group consists of metals which are good conductors of electricity. Their electrical conductivity varies from metal to metal. Pure gold, silver and copper have very low resistance or very high conductivity. Electrical conductivity is the inverse of electrical resistance and is defined as the current passing through a piece of metal, 1 centimetre cube, between two parallel faces, across which one volt potential difference is maintained. The electrical conductivity of gold and copper is 4.7×10^5 and 1.2×10^5 ohms^{-1} cm^{-1}, respectively. Other metals such as zinc,

iron or lead have electrical resistances which are higher, that is, their conductivity is lower than that of gold or copper None the less they are also good conductors of electricity.

The second group of elements in their pure form at room temperature, such as sulphur and iodine, have an extremely poor ability to conduct electric current They are often used as insulators because of this property. These elements are bad conductors of electricity

There is a third group of elements which are neither good conductors of electricity nor good insulators, they are called *semi-conductors* Their resistances lie in between those of insulators and good conductors (e g , about $1\Omega cm^{-1}$) Germanium and silicon are examples of the semi-conductor type of elements

All the three kinds of elements form crystals Their essential differences in electrical properties have been explained in terms of the behaviour of the outer electrons of the atoms The electrons in an atom can also be thought of as a cloud of charge In a conducting crystal, the electronic charge cloud of an atom (of the outer electron orbits) overlaps to some extent that of the next atom so that the charge cloud of electrons pervades the entire regular crystal array We can also say that the outer electrons in the crystals of metallic elements have been delocalized to some extent, and these electrons are no longer associated with any particular atom. These outermost electrons belong to the entire crystal lattice This enables them to move freely within the crystal of the metal. One can picture the crystal of conducting material as being made up of positive ions, surrounded by a cloud of delocalized electrons which enable electric currents to be very easily carried

In non-metals or insulators the crystal structure is somewhat different The electrons are completely bound to the atoms and the charge cloud of electrons is restricted to the region of the atoms There is no charge cloud of electrons throughout the non-metallic crystal The electrons associated with each atom form a small localized charge cloud These individual charge

clouds do not merge into one another (Figure 1 15) An electric field, therefore, cannot
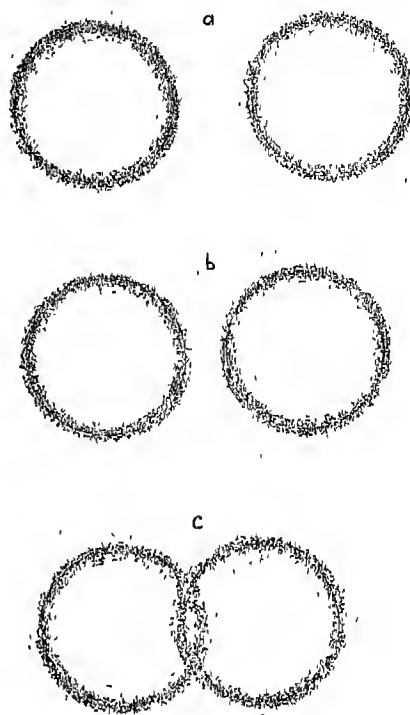
FIG 1 15 *Charge cloud of neighbouring atoms in*
    a *Insulator*
    b *Semi-conductor*
    c *Conductor*

move these electrons from one charge cloud to the next, very easily. The semi-conductor element, on the other hand, is in between the good and bad conductor, the electron charge cloud around one atom *almost* touches the electron charge cloud of the neighbouring atom This enables the electrons to jump across from one atom to the next occasionally When an electric field is applied to metals the connected charge clouds of electrons behave as free electrons, and move very easily under the influence of the electric field This appears to us as high conductivity of electricity On the other hand, in the non-metals like sulphur, the electrons' clouds are localized and not inter-

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connected, only an extremely high voltage or potential difference would enable electrons to be torn off from one charge cloud around an atom and jump to the neighbouring charge cloud. The semi-conductor comes in between the two cases

There is a very simple method of distinguishing metallic elements from semi-conducting elements If you heat a metallic wire, the resistance of the wire increases as its temperature increases. This is because on heating atoms move or vibrate around their mean position and jostle or interfere with the movement of the electrons This prevents, or rather reduces, the free movement of electrons in a metal when an electric field is applied. In the semi-conductor, on the other hand, an increasing temperature will cause vibrations of the atom and of the electron charge cloud This will cause neighbouring electronic charge clouds to come closer and finally merge into one another for a part of the time so that the electric current flow becomes easier on the application of electrical potential differences Thus, in a semi-conductor the resistance decreases when the element is heated This is a very easy method for distinguishing semi-conductors from conductors and can be tried out in the laboratory

There is a very simple way of putting all the chemical elements in one chart This chart is called the Periodic Table The chemical elements in this chart are arranged in order of the total number of electrons that each type of atom contains For example, the atom of the first element—hydrogen—in the chart contains 1 electron and a nucleus The second element is helium Its atom contains 2 electrons moving around the nucleus You would also notice in the chart that elements which have similar properties, occupy positions in the same vertical column. For example, all the metals which have similar properties, such as sodium, potassium, cesium, are arranged vertically, one below the other Similarly, elements like flourine, chlorine, bromine, etc, are arranged vertically in one column If you study the Periodic Table very

carefully, you will notice that the elements which are metallic occupy the left-hand side of the periodic table and non-metallic elements like sulphur, iodine, etc, occupy the right-hand side of the Periodic Table The semi-conducting elements, which we have discussed, would be in positions that are in between the two groups of conducting and non-conducting elements in the Periodic Table

Let us now study some of the common metals with which you are all familiar, viz, copper, aluminium, iron, silver, etc. You will notice that copper, iron and silver are quite heavy If you rub any of the metals with a piece of sand-paper, you will expose a shiny bright surface This is another common characteristic of most metals Almost all the metals are solid (consisting of extremely small crystals). The only exception is mercury, a metal which remains liquid at room temperature However, mercury is a good conductor of electricity and quite shiny Other metals which you come across quite frequently are zinc, nickel, magnesium, gold, tungsten, etc Take a piece of any common metal and put it in water You will notice that it will sink to the bottom These metals do not dissolve in water However, if you take a piece of copper or zinc and pour a little hydrochloric acid over it, you will notice that there is some effervescence, and gradually the zinc or copper disappears Thus we can say that many metals dissolve in acids Strictly speaking, however, they do not dissolve in the acid but a chemical reaction takes place Metals can be burnt in oxygen to form metallic oxides Oxides of metals when in contact with water show properties of alkalinity This is quite easy to test If you burn a piece of sodium in air and dissolve the residue, which is an oxide, in water and put a piece of red litmus paper in it, you will find that the litmus has turned blue

The non-metallic elements on the other hand are sulphur, iodine, oxygen, nitrogen, etc You will notice that in general the non-metals are lighter, i e, they are less dense than the metals Some of the non-metals are gases at room tem-

perature, like oxygen or nitrogen Most of the non-metals, like sulphur and iodine, can be dissolved in the appropriate liquids. Sulphur gets dissolved in carbon disulphide (CS_2) and iodine in methyl alcohol (CH_3OH) However, sulphur and iodine cannot be dissolved in hydrochloric acid, like metals. You can burn sulphur to form oxides of sulphur such as sulphur dioxide (SO_2) which will dissolve in water quite easily The solution turns blue litmus red The non-metal oxides are, therefore, acidic There are some oxides of metals or near metals which behave as metals in some cases and non-metals in other cases A very common example is aluminium You can burn it in oxygen to form aluminium oxide Al_2O_3 dissolves in acids as well as bases You will find that salts can be formed from aluminium oxide. The sodium salt is called sodium aluminate. Compare this with the salt formed from sodium and the oxide of sulphur in the presence of water. In this case you will get sodium sulphate (Na_2SO_4) The behaviour of aluminium is somewhat similar to sulphur in this case On the other hand, you can take powdered aluminium and dissolve it in sulphuric acid to form aluminium sulphate. In this case aluminium behaves like a metal Such metals which have a twofold behaviour are called *amphoteric* and the oxide of aluminium is called an amphoteric oxide because of its dual behaviour

IV. Electronic structure—chemical and physical properties

To understand the valency and combining power of elements, we should know how the atom is put together To recount briefly, we recognize four basic features of an atom:

1 The diameter of an atom is between 10^{-8} and 10^{-7} cm

2 The atom is composed of a nucleus whose volume is extremely small (about 10^{-15} of the volume of an atom)

3 The density of nuclear matter is very high It is about 10^{13} times denser than gold or uranium and it can carry a positive charge.

4 The nucleus is surrounded by negatively charged electrons which occupy the entire volume of the atom These negative electrons surrounding the atom determine the chemical properties of an atom

To understand this further, we must know something about the structural arrangement of the electrons and their behaviour when atoms approach one another with sufficient energy to interact

The electrons surrounding the atom do not behave like ordinary charged particles and cannot be observed in a laboratory As a result of Niels Bohr's work we now know that the electrons in an atom occupy specific energy levels. It is usual to number these energy levels as 1, 2, 3, 4, etc. Corresponding to each energy level, the electron is supposed to go round the nucleus in a certain orbit These orbits of the electrons are called K, L, M, N, etc., and the corresponding number n = 1, 2, 3, 4 is called the 'principal quantum number' of the electrons in the atom Another basic and important rule of the quantum theory which developed out of Bohr's work was that the number of electrons that can occupy a particular orbit or energy level is equal to $2n^2$ Thus the first energy level or the orbit is completely filled with 2 electrons, the second or the L orbit with 8 electrons, the third or the M orbit with 18 electrons, and so on However, in the outermost orbit eight electrons give a stable structure Sometimes the K orbit is also called as the K shell, the L orbit as the L shell, etc

When an atom interacts chemically with another atom, it is only the electrons in the outermost orbit that play an important role The rearrangement of electrons in the outer orbits of two or more atoms results in the formation of chemical compounds or molecules For example, lithium has only one electron in the second orbit, sodium has only one electron in the third orbit Similarly, potassium, rubidium, cesium have only one electron in their outermost orbits These outermost electrons are quite far away from the nucleus, and they are easy to
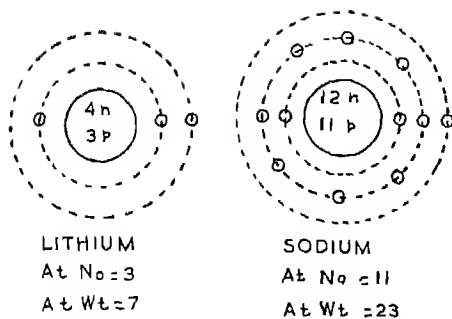
FIG 16a *Arrangement of electrons in orbits lithium and sodium*

remove, as they are weakly bound On the other hand, fluorine has 7 electrons in the outermost orbit, i e , 1 less than the 8 required to fill it up completely. Similarly, chlorine, bromine and iodine also have only 1 electron less than the 8 necessary to fill their outermost orbits com-
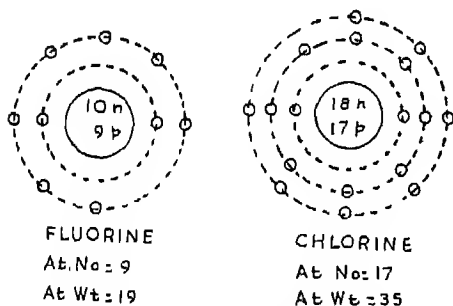
FIG 1 16b *Arrangement of electrons in orbits fluorine and chlorine*

pletely These atoms, therefore, tend to capture electrons quite easily to form a complete shell of electrons in their outermost orbits In the language of the chemists, we can say that the alkali atoms, i e , atoms of lithium, sodium, potassium, etc , easily form positive ions by losing one electron; the halogens, i e , fluorine, chlorine, bromine, easily form negative ions by adding one electron to their outermost orbit Positively charged sodium ions and negatively charged chlorine ions attract each other because of their unlike electric charges This is called the

attractive force of the ionic bond between sodium and chlorine These attractive forces of the ionic chemical bond give rise to the sodium chloride molecule The oppositely charged sodium ion and chlorine ion cannot approach each other beyond a certain distance because both have negative electrons moving around the nuclei of these atoms These negative charges in both sodium and chlorine atoms prevent these atoms from coming very close to each other The result is that the sodium and chlorine atoms take up an equilibrium position where the opposing electrostatic forces are balanced This equilibrium distance between sodium and chlorine atoms is called 'interatomic distance' Because of the position of equilibrium between two atoms we can speak about atomic and ionic radii.

Covalent Bond Many compounds have covalent bonds This type of interatomic force arises from the fact that individual atoms can gain a 'closed shell electron structure' in their outermost orbits by sharing the electrons with other atoms Physicists and chemists often explain the phenomenon of the jumping of electrons from the orbit of one atom to that of another in the covalent bond by saying that the electrons forming covalent bonds are most likely to be found somewhere in between the atoms The covalent bond arises from the electrostatic attraction, not between the positive and negative ions but between the individual positive ions and the negative charge cloud of two or more electrons located between two ions For example, in the hydrogen molecule each hydrogen atom has two electrons in its first orbit a part of the time, averaging to one electron over a long time. Since two electrons are needed to fill the first orbit, this results in a closed shell structure of the hydrogen atom for a part of the time, giving a higher binding energy than the (one) electron attached to the hydrogen atom over a long time

The forces of the interatomic bond, whether it is ionic or covalent, can be measured experimentally by measuring the energy that is re-

leased in forming molecules out of the consti-
tuent atoms

If a suitable solvent for a substance is found,
it is fairly simple to determine experimentally
whether the chemical bond is ionic or covalent
in character Covalent molecules do not separate
into positive and negative ions in a solution,
i e , they do not ionize in a solution The re-
sistance to current flow is not lowered by adding
a covalent compound to a solvent (This is easy
to demonstrate experimentally) When the bond
between the atoms is ionic, molecules separate
into positively and negatively charged ions or
groups of atoms carrying a charge. The negative
and positive ions act as conductors of electricity
and these solutions of ionic compounds show
increased electrical conductivity on the addition
of a compound to the solvent A compound
which causes increased electrical conductivity
of a solution is also called an electrolyte because
electrolysis of such a solution is possible For
example, hydrogen gas is very often prepared
by electrolysis of an acid such as hydrochloric
or sulphuric acid Hydrogen ions being positive
appear at the negative electrode and can be
collected quite simply in an inverted measur-
ing cylinder Oxygen can also be prepared by
electrolysis and it appears at the positive elec-
trode because the oxygen ion in a solution is
negatively charged

If you measure the electrical resistance of
(i) pure distilled water solution, (ii) a solution of
sugar in the same water, and (iii) a solution of
common salt, i e , sodium chloride, you can note
the difference in resistance in each case by ob-
serving the current flowing through the cell

In a solid, molecules usually arrange them-
selves in regular patterns. For example, if you
take crystals of a compound with ionic bonds,
exchange of electrons between the ions will take
place within the crystal and therefore the
positive and negative ions will tend to alternate
with each other in the arrangement Let us take
sodium chloride as an example. Since the
sodium atom is positively charged and the
chlorine atom is negatively charged, each atom
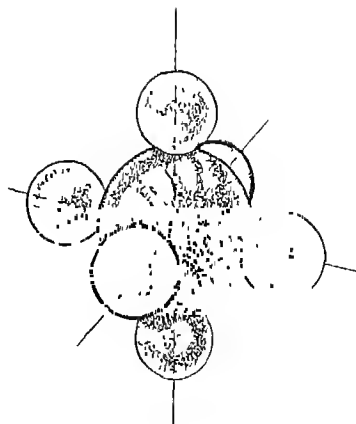
Fig 1 17   *Arrangement of ions of sodium
chloride crystal*

will alternate with the other. This will give rise
to an arrangement as shown in Figure 1 17 The
cubical arrangement of the sodium and chlorine
ions in the crystal of sodium chloride is called
the cubic lattice More complex substances with
ionic bonds (such as $CaSO_4$) will form more
complex crystals. A study of ionic compounds
will show that they have many properties and
will help us to summarize them

1 Ionic compounds form hard, usually
   brittle, crystalline solids at room tempera-
   ture
2 They usually have high melting points
   because it takes a great deal of energy to
   pull apart oppositely charged ions In the
   solid state they are not good electric con-
   ductors but when melted or fused ionic
   compounds conduct electricity freely be-
   cause the charged ions are then free to
   move in an external electric field A
   solution of ionic compounds in water
   conducts electricity because in a solution
   free ions are easily formed

A compound having covalent bonds also
forms crystals. In the solid form, however,
crystal lattices are made up of neutral atoms
or molecules.

Other general properties of covalent com-

pounds containing the covalent bond can be summarized as follows .

1. They are usually gases, liquids or solids at room temperature and their crystal lattices are usually more complex

2. The compounds containing covalent bonds usually have low melting points because of the smaller intermolecular attractive forces.

3. They are usually not very soluble in water but quite soluble in organic solvents

4. They are usually poor conductors of electricity since the molecule and not the ion is the basic unit

You would notice that almost all the substances which are formed due to ionic or covalent bonds are crystals in the solid state There are other kinds of bonds which we have not discussed However, these other types of bonds also lead to the crystalline structure of their solid compounds One particular case is the metallic bond It is necessary to note in the case of metals that there is a special kind of bond called the metallic bond in which the outermost electron or electrons are free and form a cloud of particles throughout the volume of the metal These electrons then are no longer associated with a particular atom or molecule. They are delocalized and are associated with the entire piece of the metal This gives rise to a special kind of force in a metallic crystal, known as the metallic bond Here the electrons move about freely in the entire body of the metal Metals are characterized by very low electrical resistance, i.e., very high electrical conductivity

V. Energy of molecular formation

We have already stated that when the molecule is formed, the electrons in the outermost shell and the atoms concerned in the chemical reaction rearrange themselves We can now define a chemical reaction as a rearrangement of the outer electrons of the atoms which combine

together to form a molecule The energy of the interatomic forces of the bond can be measured in terms of the energy that is required to separate the atoms or to break the bond This energy is usually measured in units of calories required for the separation of a particular bond per gramme molecule of the substance Sometimes certain bonds are very unstable and energy is given out rather than absorbed when such a bond is broken

An exothermic chemical reaction is one in which energy is released (usually in the form of heat) in the formation of a molecule and is measured in calories per gramme molecule. A gramme molecule is the weight of 6×10^{23} molecules For example, 22 4 litres of hydrogen at room temperature would contain 6×10^{23} molecules of hydrogen and weigh 2 grammes (molecular weight in grammes-gramme-molecule)

A chemical reaction in which energy is absorbed in the formation of molecules is called an endothermic[3] chemical reaction The product of an endothermic chemical reaction is usually unstable, i e , the molecules formed by the endothermic reaction can easily break up into their components, and in the process yield an equivalent of the amount of energy that was absorbed to form the molecule, for example, in explosives like T N T (tri-nitro-toluene) The molecules of these substances are unstable When they break, they release energy.

One of the simplest and very common chemical reactions is the combining of carbon and oxygen to form carbon dioxide (CO_2) The reaction is sometimes written as $C + O_2 = CO_2 + 94,000$ cal This means that when 12 gms of carbon combine with 32 gms of oxygen to form 44 gms of carbon dioxide, 94,000 calories of heat are released We burn coal at home for cooking, in steam engines for pulling railway

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[3] The terms 'exothermic' and 'endothermic' have a Greek origin and mean respectively 'giving out heat' and 'taking in heat' Sometimes the terms exoergic and endoergic, meaning 'giving out energy' and 'taking in energy', are also used

trains and in generating stations for producing electricity Even in our own body, when we oxidize food, we take in oxygen as we breathe in or inhale air, and exhale the product of combustion (carbon dioxide) The basic chemical reaction that is taking place in each case is the same In fact, we can measure the amount of energy we obtain from our food by measuring the amount of carbon dioxide we exhale We can measure the amount of electricity we generate by calculating the amount of coal burnt to produce that electricity However, in the case of steam locomotives and electricity generating stations, all the heat that is produced by burning coal is not turned into electricity or traction power; some of it is invariably lost

Energy is also associated with dissolving a solid or a liquid in water This is called the heat of the solution For example, if you dissolve a little sulphuric acid in water, you will find that the water containing sulphuric acid becomes warm If you dissolve ammonium chloride (NH_4Cl) or potassium nitrate (KNO_3) in water you will notice an opposite effect In dissolving ammonium chloride or potassium nitrate the water becomes cooler The name given to the heat released, as in the case of sulphuric acid, or the heat absorbed, as in the case of potassium nitrate, is the heat of the solution The heat of the solution may be positive or negative

We have already mentioned, that within the human body as well as in animals, combustion of carbon to form carbon dioxide is going on all the time In fact, the heat that is obtained from this combustion is what keeps animals and human beings warm The rate of combustion in the human body is very well regulated and is such that the temperature of the human body remains even Both carbon and oxygen are necessary for the human and the animal bodies Oxygen is provided from the air, when an animal or a human being breathes The source of carbon is the food, particularly sugar, carbohydrates and fats that men and animals eat

Whether it is an electric generating station or our food, or whether it is a car, bus or railway train, the power that we are using is primarily the heat and energy obtained by burning carbon and forming carbon dioxide This heat is converted into mechanical energy in the case of steam engines or rotating generators (dynamos) which in turn produce electric power

VI. Energy and its transformation

You have already seen a number of examples of how one type of energy is transformed into another The burning of coal which yields heat is the chemical combination of carbon with oxygen You have also noticed how the mechanical energy rotating the electric generators gives electricity in the form of electric current. In a steam locomotive, coal is burnt to provide steam at high pressure in a boiler This steam drives the locomotive through the movement of a piston in a cylinder, to which the wheels are connected by a set of levers

It is a general rule that you can transform one form of energy into another There is a very simple law about this This law states that the quantity of any form of energy is exactly equal to its equivalent quantity in any other form All physical happenings, whether they are processes going on in the stars through millions of years or whether it is the motion of a cricket ball or of an ant, are essentially processes in which the transformation of energy from one form to another takes place To the best of our knowledge and experience, the total energy in a region changes only when an exchange of energy occurs between the region and its surroundings In other words, our physical experience is consistent with the universal conservation of energy If we take our region as the entire universe, then we should expect no change of the total energy because by our definition there is nothing outside the universe The assumption that the total energy of the universe is constant is the basis of most

theories about the evolution of stars and galaxies of this universe

The unit of mechanical energy usually used is called the joule. The joule is defined as follows:

One joule is the work done when a force of one newton moves a body of mass 1 kilogram through 1 metre

There are two other simple forms of energy—electrical and heat energy A unit of electrical energy is a kilowatt-hour This is the unit that is used for measuring the amount of electric energy consumed in every home Your electric bill from the electric supply corporation states how many units of electricity have been consumed during the month, this unit is the kilowatt-hour

The mechanical energy measuring unit, the joule, is related directly to the electrical unit of energy, the kilowatt-hour, by the following relation.

1 kWh (kilowatt-hour) = 3.6×10^6 joules

The unit of heat energy is called the calorie. One calorie is the amount of heat energy which raises the temperature of 1 gramme of water by 1°C The calorie measures heat energy and the joule measures mechanical energy Very often we use, in practice, the rate of doing work or the rate of energy expenditure, which is called power For example, the power of one joule per second is equal to 1 watt

There are many forms of energy We have only mentioned heat, electrical and mechanical energy, Electromagnetic radiation is another form of energy Electromagnetic radiations can be subdivided into radio waves (both short and long), infra-red radiation, ultra-violet radiation, X-rays and gamma rays Other forms of energy are electric currents and fields, magnetic fields, the energy of electric charges, chemical energy, energy of sound waves, and nuclear energy Each of these forms of energy can be converted into any other form. One can calculate the amount of energy that will be equivalent to any other form of energy by using a multiplication constant which is called the

transformation constant of one form of energy to another

The energies of heat, light or sound are examples of energies in action There are other kinds of energy, viz., the energy of water stored in a reservoir or in a tank at the top of a building This energy is called potential energy and is measured exactly in the same way as any other form of energy There are many examples of potential energy or stored energy, such as the energy of a spring that has been wound up, e g, the spring of a clock The water stored at a height provides an example of potential energy, while falling down it can turn wheels or turbines and generate mechanical and electrical power There is also electrical potential energy A simple example of stored electrical energy or potential energy is a charged condenser If you charge a condenser and then discharge it through a tube filled with neon gas at a low pressure, you can see a flash of red light through the tube This flash of red light is due to the electric current flowing through the neon gas In other words, the energy of the charged condenser (the electrical potential energy) is converted first into electric current and then into heat and the light of the neon gas.

Potential energy is measured in the same units as kinetic energy When we talk of the conservation of energy, all forms of energy—kinetic and potential, electrical, magnetic or chemical—have to be taken into consideration Energy is conserved in a system only when all possible forms of energy in the system are taken into consideration

In an atom bomb, in a star, and in a nuclear reactor, nuclear energy is converted into heat The energy of the nucleus resides in the mass of the nucleus In the release of nuclear energy a part of the mass of the nucleus is converted into energy The great scientist, Albert Einstein, showed that mass can be converted into energy and *vice versa*, the law of transformation in this case is exactly similar to the law of transformation of one form of energy into another The

law of conversion of mass into energy, as formulated by Albert Einstein, is

Energy = mass × (velocity of light)²

or, 9×10^{16} joules = 1 kg × $(3 \times 10^5$ metres/sec$)^2$ We have similar transformation laws that connect every form of energy as well as mass to one another (see Table 1 1) Man utilizes some of these forms of energy in large quantities For example, the chemical energy of coal or oil is used very extensively by man We burn coal or oil to get heat, electrical power or mechanical power for various uses Over 90 per cent of the energy that man uses is the energy of coal, oil, and water placed at a height

The most important source of energy for man on earth is the energy of the sun This energy is generated in the sun through the transformation of a small fraction of the mass of the sun into energy The sun's energy not only gives us heat and light, but also energy which produces chemical reactions (mainly) in plants to produce food The green leaves of plants are the main source of the chemical reactions using the sun's energy to synthesize, out of water and carbon dioxide, the food on which both animals and plants depend Coal is also a form of energy Millions of years ago, the earth, particularly in marshy regions, was full of trees These extensive forests were buried eventually and fossilized Coal is the fossils of these forests of the past, commonly called the forests of the carboniferous era of the earth

You all know of the attraction of the earth for all bodies In fact, every body in the universe attracts every other body This force of attraction is called gravitation The sun attracts the earth The earth attracts the sun and the moon We do not normally notice this force as very little change takes place in the action of this gravitational force. However, the variation of the attractive forces of gravitation of the sun and moon on the earth results in tides in the ocean These tides are due to the fact that the sun and moon try to pull out water which, being a fluid, moves slightly outwards The variation in the force occurs be-

cause the earth rotates on its own axis and therefore different parts of the earth face the sun or the moon The relative position of the moon and the sun also changes, so that at times the sun and the moon pull together in the same direction giving rise to extra high tides The tides raise the height of the water and increase the potential energy of the water. Many scientists and engineers have suggested that if one could capture the water at its high level and allow it to fall carefully through a turbine, one could get power out of the tidal energy, i.e., the gravitational energy of attraction of the sun and the moon Quite recently this idea has been put into practice on a small scale at Rance in France Rance is the estuary of a small river and during high tide the water runs up the estuary Engineers have constructed a dam whose gates are kept open when the water is flowing up the estuary When the water reaches its highest point the gates of the dam are closed, and the water captured in the estuary is allowed to flow back through the turbines, generating electric power

Since the discovery of uranium fission, the energy of the nucleus of the atom released in fission has been put to use in nuclear reactors These reactors can produce heat and electricity The first reactor which will generate electric power from the fission of uranium in India is being constructed at Tarapur in Maharashtra, and the second will be near Kotah in Rajasthan These power stations will use uranium and produce electric power at the rate of 500,000 to 1 million kilowatts To a small extent this will free coal from its use as a fuel. The coal thus saved can be put to other uses such as the production of useful chemicals like dyes, benzene, napthalene, etc

TABLE 1.1

The law of conservation of energy can be confirmed by measuring each amount of energy before and after its conversion Directly or indirectly, the different forms of energy can be measured.

Some of the well-known relationships used in the

measurement of the different forms of energy are given below

Mechanical potential energy of a body
= (mass) × g × (height)

Mechanical kinetic energy of a body
= $\frac{1}{2}$ (mass) × (velocity)^2

Heat energy for change of temperature
= (mass in kg) × (sp heat) × (change of temperature in degrees centigrade) = kilo-calories

Heat energy for change of state
= (mass in kg) × (latent heat of fusion/vaporization) = kilo-calories

Electrical energy
= (amperes) × (volts) × (seconds) = watt × second
= (amperes)^2 × (ohms) × (seconds) = watt × second

kilowatt × hour units = $\frac{(\text{watts}) (\text{hours})}{1000}$

Nuclear energy = (mass in gm) (3 × 10^{10})^2 ergs
= (mass in kg) × 9 × 10^{16} joules

A kilo-calorie is equal to 1000 calories, while a calorie is defined as the heat required to raise the temperature of 1 gm of water by 1°C A kilo-calorie is also written as Calorie (with a capital C)

The law of conservation of energy is indirectly proved by the transformation constant which connects the numerical energy of one form to the energy of another form For example

(a) The unit of heat energy is a calorie, while
1 calorie = 4 2 joules
= 4 2 × 10^7 ergs

That is, we can get one calorie of heat out of 4 2 joules of work and *vice versa*

(b) The unit of electrical energy is watt × second, while
1 watt × sec = 1 joule
1 kilowatt × hour = 1000 × 3600 joules
= 3 6 × 10^6 joules

(c) The conversion constant of mass into energy is given by
1 kg × (3 × 10^8 metres/sec)^2 = 9 × 10^{16} joules

(d) When electrical energy is to be converted into heat, then heat energy = $\frac{\text{watts} \times \text{seconds}}{4 2}$ calories

Example In a waterfall, the water falls from a height of 100 metres Calculate its rise in temperature

Let m gm be the mass of water falling and t°C be the rise of temperature Then

Mechanical potential energy of water
= m × g (100 × 100) ergs
= m × 981 × 10000 ergs

Heat produced
= m × 1 × t calories,

Then 4 2 × 10^7 × m × t
= m × 981 × 10000
t = $\frac{981 \times 10000}{4 2 \times 10^7}$ = 0 23°C

Example Calculate the amount of a monthly bill for using two 100-watt bulbs for 5 hours a day, one ceiling fan of 200 watts for 10 hours a day and a 250-watt radio for 4 hours a day, when the electricity costs 20 paisa per unit

Here, watt × hours per day for 2 bulbs
= 2(100) × 5 = 1000

watt × hours per day for 1 fan
= 200 × 10 = 2000

watt × hours per day for 1 radio receiver
= 250 × 4 = 1000

Total electrical energy used per day
= 4000 watt × hours

Hence total electrical energy used per month
= 4000 × 30 watt × hours

kilowatt × hour units used = $\frac{4000 \times 30}{1000}$ = 120

Amount of the monthly bill = 120 × 20 paisa
= Rs 24 00

VII. Engines

Engine is a word which has a special meaning when used in science and technology. The use of the principles of physics to make useful tools for man is called 'engineering' However, the word *engine* means a device that transforms one form of energy into another For example, the heat engine is a machine that can be used to transform heat into mechanical energy A steam engine, particularly a railway traction steam engine, converts the heat of burning coal into the mechanical energy of the motion of the railway train Another kind of heat engine is the internal combustion engine which transforms heat by the combustion of petrol or diesel oil into the mechanical energy of the motion of the motor car, bus or truck

Similarly, atomic engines or nuclear engines transform the heat energy of nuclear processes such as fission into the mechanical energy of motion For example, the power reactor that is being built at Tarapur will convert the heat generated as a consequence of the fission of uranium in the reactor into high-pressure and high-temperature steam which will drive the

3

turbines These large rotating turbines will in turn drive a dynamo or an electric generator to produce electrical power In this sense the dynamo or the electric generators are engines which convert the mechanical energy of rotational motion into electrical energy In the case of electrical power we can also have engines which do the opposite We call them electric motors The electric fan is an example of an engine which converts electrical energy into the mechanical energy of rotation In many cases you will notice that what we normally call an engine is really several engines put together For example, an atomic engine is really a combination of three engines The first engine is the reactor where nuclear energy is converted into heat energy, the second is the turbine which converts the heat of the atomic reactor into mechanical rotation, and the third is the electric generator that converts mechanical motion into electrical energy.

Engines are very useful devices and are necessary for carrying out various tasks It is, therefore, important to know how useful and how good an engine is. This is usually described by the efficiency of the performance of an engine The efficiency of an engine is given by the amount of energy it delivers for a certain energy input Since an engine transforms one kind of energy into another, both the output energy and input energy of an engine have to be put into the same units of energy, before one can calculate the efficiency We thus have the following relationship

$$\text{Efficiency} = \frac{\text{Output energy}}{\text{Input energy in the same units}}$$

We have already discussed the exact nature of relationship of the different forms of energy. Theoretically, therefore, the highest value of efficiency can only be unity If efficiency could be greater than 1, energy would no longer be conserved. In effect, with efficiency greater than 1, energy could be created, but this never happens If there is no output energy, then the efficiency is zero Therefore the efficiency could vary only from zero to unity In all cases the efficiency is less than unity In all practical situations efficiency is expressed in percentages, 100 per cent being equal to unit efficiency The efficiency can therefore vary from 0 to 100 per cent.

When we generate electricity through burning coal or oil in a large, modern thermal power station, the efficiency of such generation is usually between 30 and 40 per cent If there are many stages in the transformation of energy from its initial form to the form in which it is utilized, efficiency tends to drop If we consider only the conversion of heat into mechanical energy in a modern high-pressure, high-temperature turbine, the efficiency of such conversion can be between 50 and 75 per cent Since in electrical power generation, the transformation of energy takes place in two stages—from heat to mechanical energy and then from mechanical energy to electrical power—there is a drop of 30 to 40 per cent in efficiency because the efficiency of generation of electrical power from mechanical energy is also around 60 to 80 per cent When we consider the generation of electrical power from nuclear energy, there is a further drop of 15 to 25 per cent in the efficiency because of the three stages involved.

The practical efficiency that one can achieve in an engine depends on our knowledge, on the technical skill and the ability to use the right kind of materials, and finally on the theoretical limits of the processes themselves An example of this is the steam engine, whose efficiency was only about 10 per cent a hundred years ago, increasing skill and technique and the use of steam at higher pressures has increased it to around 40 per cent today. The engines that we are trying to build today with new principles have much lower efficiency than what they would have in the future as our skill increases For example, the energy of the sun that we receive on the earth in the form of light and heat can be used by concentrating it in a small volume with lenses or mirrors It can also be converted directly into electrical energy through solar cells These are thin, suitably treated

sheets of pure silicon or germanium If such thin sheets of silicon or germanium are exposed to sunlight with electric connections between the top and the bottom surface of the silicon or germanium sheets, current flows between the two surfaces through the wire These solar cells were invented only about 20 years ago When they were first invented, their efficiency was about 4 per cent In recent years they have been improved, now the best solar cells have an efficiency as high as 15 to 16 per cent It is possible that in future solar cells may have efficiencies comparable to the other kinds of engines, and be able to convert the sunlight into electricity, cheaply and efficiently

We have described a few kinds of engines Probably the earliest amongst them is the steam engine To a large extent the steam engine is being replaced by the internal combustion engine, such as the engines of our motor cars Steam turbines are also replacing the reciprocating steam engines In a steam turbine, high-pressure steam passes through a series of blades mounted on a single axis and shaped in such a way that as the hot steam under pressure expands through the turbines, the blades rotate very fast In a modern steam turbine, the steam is allowed to condense at one end so that a partial vacuum is formed at the other On account of the pressure created at one end, the steam travels through the turbine at very high speed thus causing the blades of the turbine to rotate, also at very high speed This gives the steam turbine very high mechanical efficiency, sometimes as high as 70 to 75 per cent

The internal combustion engine is very convenient because it is very light in weight and can be attached even to a bicycle or a motor car Figure 1 18 shows the structure of the normal internal combustion engine. The normal petrol engine has four strokes Petrol or oil vapour mixed with air is introduced into the cylinder of the internal combustion engine through a system called the *carburettor* The electric spark ignites the mixture of petrol and air The combustion of petrol and the
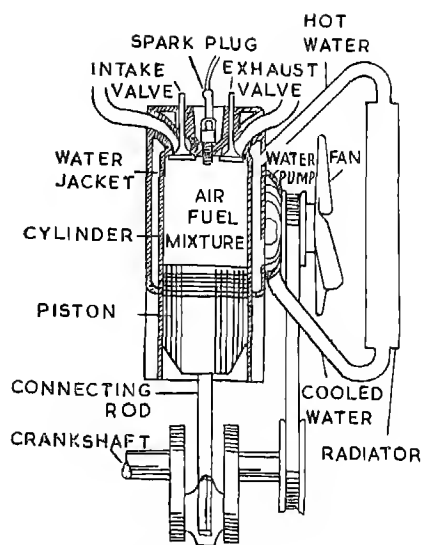
FIG. 1 18 *Diagram showing the internal combustion engine in action*

oxygen of the air, giving out heat, carbon dioxide and water vapour, push the moving cylinder The electrical spark takes place in a small spark plug inserted within the cylinder of the internal combustion engine The electric current which produces the electric spark comes either from a generator or from a battery through a distributor which is really a switch that connects the source of power to the separate spark plugs exactly at the time at which the spark is to be produced An induction coil acts like a transformer and gives the high voltage for the spark. The primary of the coil is supplied by a generator or a battery and is connected through a switch This switch is also a part of the distributor so that primary current is connected at the same time as the secondary connection of the spark plug through the distributor.

There is another class of turbine engines in which the hot gases produced by the combustion of air and fuel oil are passed through the turbine blades A very common engine of this type is the turboprop engine of an aeroplane In these cases the turbines are connected to the

FIG 1 19 *The turboprop engine The diagram shows how the turbine is connected to the propeller*
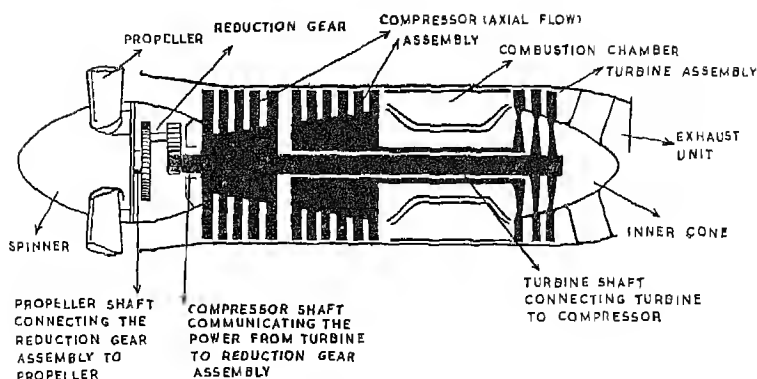
propellers of the aeroplanes (Figure 1 19). The Fokker Friendship and Viscount planes used by the Indian Airlines Corporation in India are provided with hot-gas turbine-driven propellers

There is another interesting principle which can be used for converting heat energy into mechanical motion This is demonstrated in the reaction type engines The reaction type engines depend on Newton's third law of motion which states that every action has an equal and opposite reaction. It means that if you give a certain amount of velocity or speed to a certain mass of gas or solid being ejected in one direction, the body which ejects the hot gas, gets speed or velocity in the opposite direction, the amount of which is inversely proportional to the mass of this body and directly proportional to the mass and velocity of the ejected gas or solid This law can be stated quite simply as,

$$MV = mv$$

where m, v refer to the mass and velocity of the ejected gas or particles and M, V refer to the mass and velocity of the body which ejects hot gas or particles. A very ordinary example of this phenomenon is the recoil of a rifle or a cannon when it is fired This principle can be used to build engines, the simplest of such engines are the jet engines of the modern aeroplanes These aeroplanes have no propellers but only chambers in which the fuel gases are mixed with air and are burnt The heat of combustion expands the gases to a large volume

or, rather, creates a large pressure within the chamber, and the hot gases escape through the nozzles at the rear end of the burner at high velocity The hot gases escaping with high velocity give a thrust in the opposite direction, which is the forward direction of the aeroplane Jet planes working on this reaction mechanism move at a very high speed which is quite close to the velocity of sound in air The Indian Airlines Corporation uses a make of jet plane called 'Caravelle' It has two jet engines mounted at the rear (Figure 1.20). The Indian Air Force and the air forces of other countries use a large number of jet planes because these planes are much faster than the propeller type planes Air India mainly uses Boeing 707 jet planes The speed of the Caravelle is about 560 m p h , and that of the Boeing 707, about 570 m p h Many of the jets can fly much faster than the speed of sound in air

The rocket engine is very similar to the jet engine The main difference is that jet engines use oxygen from the air for the combustion of the fuel The air is taken in through suitable openings and compressed before it is mixed with the oil vapour for combustion. In a rocket engine the oxygen that is necessary for combustion is carried by the engine itself

You should note that one cannot use a jet engine to travel in space because there is no air or oxygen available for combustion. The rocket engine, however, can be used to travel in space because the engine carries chemical subs-

tances which, reacting together, will produce the large amount of heat necessary for rocket propulsion Large rocket engines have been built, particularly by the Russians and the Americans, to take heavy loads, including men, into space These engines operate mainly with fuels such as alcohol and oxygen Recently, scientists and engineers have been trying to build rocket engines which will operate with the hydrogen and oxygen combining reaction ·

$$2(H_2)+(O_2)=2(H_2O)$$
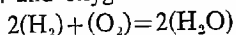
They have been partially successful The advantage of using hydrogen and oxygen as rocket fuel is that the amount of heat generated is very large; the disadvantage is that hydrogen and oxygen have to be stored in the liquid form so that the rocket carrying them is not too bulky The temperature of liquid hydrogen is very low (about 14°K) and hence it can only be obtained as a liquid with great difficulty.

VIII. Nuclear energy

We have already described an atom as something like a miniature solar system in which there is a heavy and positively charged central nucleus about 10,000 times smaller in diameter than the atom itself. There are a number of electrons which move around this heavy and positively charged nucleus, ordinarily the atom as a whole is electrically neutral

The simplest atom is that of hydrogen which consists of a positively charged nucleus carrying one unit of positive electricity called the 'proton'. There is one electron moving in an orbit around the proton in the hydrogen atom. The proton is nearly 2,000 times heavier. The atoms of heavier elements are more complicated Their nuclei are heavier, consisting of several protons and neutrons A neutron is an uncharged particle whose mass is roughly equal to that of the proton, but slightly heavier.
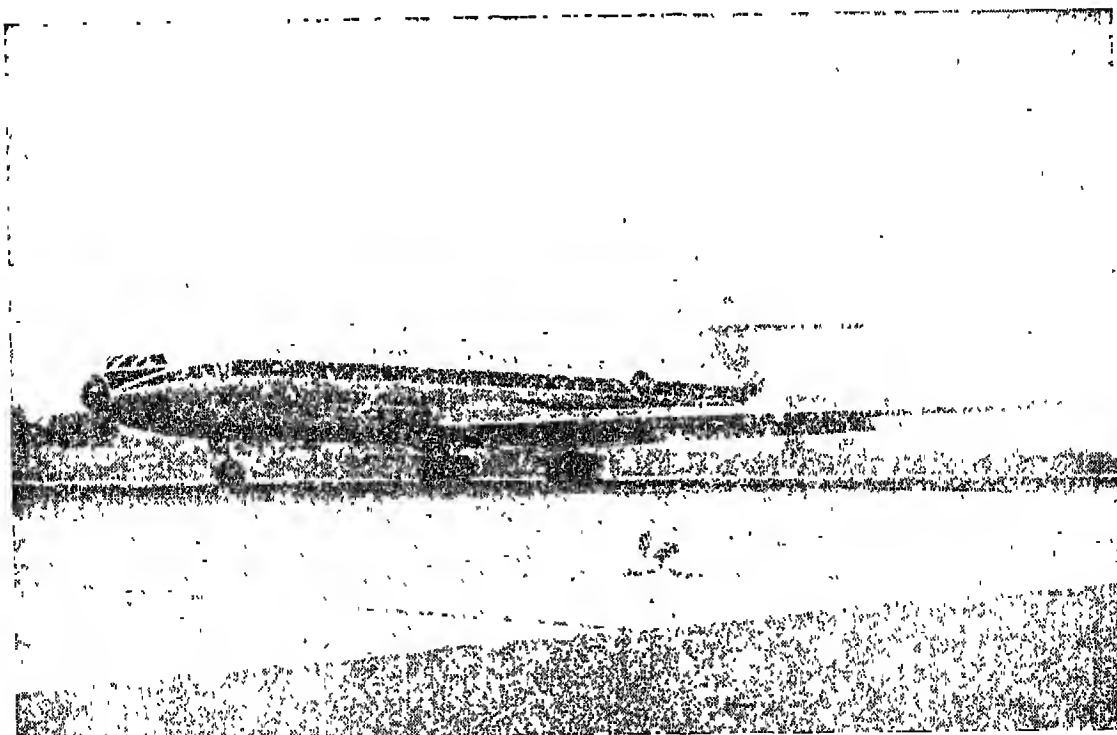
FIG. 1.20. *A Caravelle Note the left-hand side jet mounted at the rear*

The neutrons and protons attract each other very strongly and combine to form the nucleus of an atom These nuclei are also on the average quite small compared to the atom The nuclei of atoms vary in size The smallest is the nucleus of the hydrogen atom and the largest is that of the uranium atom, whose nuclear radius is around $4\,8 \times 10^{-15}$ metres. The nuclei of the atoms can contain the same number of protons but a different number of neutrons Since the number of protons is the same, such atoms carry the same number of positive charges in their nuclei. The masses of the nuclei will be however different since the number of neutrons is different Since these atoms have the same positive charge although they have different masses, they will exhibit the same chemical properties These different atoms of the same chemical element having different masses are called 'isotopes' This means that there will be chemical elements which have different atomic weights. Isotopes are quite common in nature and almost every chemical element, with a few rare exceptions, has isotopes Even the element hydrogen has two stable isotopes The first isotope is the one having a nucleus of a single proton, the second isotope, sometimes called heavy hydrogen, is the one containing 1 proton and 1 neutron in its nucleus About 0 02 per cent of the hydrogen in nature is heavy hydrogen Heavy hydrogen has often been called deuterium Hydrogen has a third isotope called tritium Study the table of isotopes (Table 1 2) and find out the number of isotopes of the odd-atomic-number elements and then of the even-atomic-number elements You will notice that the even elements have a much larger number of isotopes than the odd elements

We have already come across the law of conversion of mass and energy A direct proof of the conversion of mass into energy was obtained in 1933 after the discovery of the positron The positron is a particle which carries a unit positive charge and has a mass exactly equal to the mass of the electron. These particles were first discovered in cosmic radiation but are now quite easily produced in the laboratory

When a positron hits an electron directly both of them vanish, with the complete conversion of their masses into energy This energy is radiated in the form of electromagnetic radiation which is quite similar to the radio waves, but has a frequency which is 10^{14} times greater than the ordinary radio waves The energies of these electromagnetic radiations have been measured The total energy radiated shows that the entire mass of the positron and electron is exactly equal to the total energy of the electromagnetic radiations emitted, in accordance with the relationship of Einstein

If you have half a milligram of electrons and half a milligram of positrons, the total amount of matter would be 1 milligram, and they would be completely annihilated by coming into contact with each other The radiated energy that is evolved would be about the same as one would get by the combustion of 1 tonne of coal to form carbon dioxide In other words, if you burn one thousand kilograms of coal, you would get as much energy as you would by the complete conversion of one milligram of matter into energy

We have already mentioned that the electron is 1/2000th times lighter than the proton In other words, in about 1 milligram of matter approximately 99 98 per cent of mass is concentrated in the nucleus and less than 0 02 per cent in the mass of the electrons If you want to obtain a large amount of energy by converting matter, it would be sensible to try and convert the nuclear mass into energy rather than to convert the mass of the electrons into energy This is not only sensible, it also happens to be easier to convert a part of the mass of the nucleus into energy than to convert the mass of the electrons into energy.

In the laboratory the scientists have investigated the interaction due to the collisions of the fast moving nuclei with one an-

TABLE 1.2

SOME IMPORTANT ELEMENTS WITH THEIR STABLE ISOTOPES

Element	Atomic No	No of Isotopes	Element	Atomic No	No of Isotopes
Hydrogen (H)	1	2	Silver (Ag)	47	2
Helium (He)	2	2	Cadmium (Cd)	48	8
Lithium (Li)	3	2	Indium (In)	49	2
Beryllium (Be)	4	1	Tin (Sn)	50	10
Boron (B)	5	2	Antimony (Sb)	51	2
Carbon (C)	6	2	Tellurium (Te)	52	8
Nitrogen (N)	7	2	Iodine (I)	53	1
Oxygen (O)	8	3	Xenon (Xe)	54	9
Fluorine (F)	9	1	Cesium (Cs)	55	1
Neon (Ne)	10	3	Barium (Ba)	56	7
Sodium (Na)	11	1	Lanthanum (La)	57	2
Magnesium (Mg)	12	3	Cerium (Ce)	58	4
Aluminium (Al)	13	1	Praseodymium (Pr)	59	1
Phosphorus (P)	15	1	Neodymium (Nd)	60	7
Sulphur (S)	16	4	Samarium (Sm)	62	7
Chlorine (Cl)	17	2	Europium (Eu)	63	2
Potassium (K)	19	2	Gadolinium (Gd)	64	7
Calcium (Ca)	20	6	Terbium (Tb)	65	1
Chromium (Cr)	24	4	Dysprosium (Dy)	66	7
Manganese (Mn)	25	1	Holmium (Ho)	67	1
Iron (Fe)	26	4	Erbium (Er)	68	6
Cobalt (Co)	27	1	Thulium (Tm)	69	1
Nickel (Ni)	28	5	Ytterbium (Yb)	70	7
Copper (Cu)	29	2	Lutetium (Lu)	71	1
Zinc (Zn)	30	5	Hafnium (Hf)	72	6
Bromine (Br)	35	2	Tantalum (Ta)	73	2
Krypton (Kr)	36	6	Wolfram Tungsten (W)	74	5
Rubidium (Rb)	37	2	Rhenium (Re)	75	2
Strontium (Sr)	38	4	Osmium (Os)	76	7
Yttrium (Y)	39	1	Iridium (Ir)	77	2
Zirconium (Zr)	40	5	Platinum (Pt)	78	6
Niobium (Nb)	41	1	Gold (Au)	79	1
Molybdenum (Mo)	42	7	Mercury (Hg)	80	7
Ruthenium (Ru)	44	7	Thallium (Tl)	81	2
Rhodium (Rh)	45	1	Lead (Pb)	82	4
Palladium (Pd)	46	6	Bismuth (Bi)	83	1

other Their experiments have shown that in some of these collisions (of one nucleus with another) the energy released is small and requires very careful experiments to detect it. However, it is small because the nucleus itself is a very small thing and the mass of the hydrogen atoms and the atomic nuclei is also quite small. For example, the mass of the hydrogen atom is 1.6×10^{-24} gm and for fairly heavy nuclei such as strontium the mass is about 10^{-22} gm. The energy released, therefore, is quite small when you take only one single nucleus of an atom into consideration. However, the study of these nuclear reactions in the laboratory has showed the possibility of certain exoergic reactions, involving the nuclei of the atoms of hydrogen, carbon, nitrogen, oxygen, which would yield energy These reactions are, in all possibility, responsible for the generation of energy in the sun The energy generated by these reactions, involving a large number of nuclei, heats up the entire mass of the sun so that the centre of the sun has a temperature of about a few million degrees centigrade while the surface of the sun is at 6000°C These heat reactions or fusion reactions are responsible for the large energy that the sun emits These heat reactions also occur in most of the stars that we see in the sky.

There is another kind of nuclear reaction which yields energy This is called the nuclear fission reaction which was discovered comparatively recently in 1938. Such reactions occur only in very heavy nuclei such as those of uranium or thorium The last three elements in the Periodic Table are those with the atomic numbers 90, 91, 92 They are thorium, protactinium and uranium The nuclei of these elements are quite heavy, consisting of about 90 to 92 protons and 135 to 146 neutrons These heavy nuclei, when hit by sufficiently high energy particles, break up into two fragments very much in the way that a drop of liquid breaks into two droplets when given a shake Such reactions are called fission reactions because the heavy nuclei break into two almost equally

large fractional nuclei. The heaviest element occurring in nature is uranium, with atomic number 92 There are two main isotopes of uranium, viz, Uranium^{238} and Uranium^{235} Uranium ^{238} is present to the extent of about 99.3 per cent and Uranium^{235} to the extent of 0.7 per cent

Otto Hahn of Germany discovered fission by his painstaking investigations into what happens when uranium is exposed to a beam of neutrons From a sample of pure uranium, Hahn and his colleagues were able to detect chemically other elements such as barium, krypton, etc. The experiment of Hahn and others established that a large amount of energy was released during fission, equivalent to about 1/1000th of the total mass of uranium This energy is quite large and is about one million times the energy released in the combustion of an equal amount of coal The work of Hahn, Joliot Curie and others also demonstrated that during the fission of uranium, 2 or 3 extra neutrons are released Since the fission of uranium can be caused by neutrons hitting a uranium nucleus, Fermi, another great physicist, thought that the neutrons that are released during the fission could be used to produce more uranium fission Such an arrangement, called a chain reaction, can be produced by utilizing the neutrons obtained from uranium fission to cause further fission of the uranium nuclei. Fermi's investigations showed that this chain reaction could be set up very easily with the isotope Uranium^{235}. He was also able to show that even in ordinary uranium with only 0 7 per cent Uranium^{235}, it was possible to set up chain reactions by using large quantities of very pure uranium and very pure graphite or heavy water arranged in such a way that the neutrons are not lost but slowed down and captured to cause further fissions in the uranium This arrangement was called a *nuclear reactor* by Fermi

The fission of uranium, in which the nucleus of the uranium atom on being hit by the neutrons breaks into two fragments, can be compared

to the breaking up of a large drop of liquid into two drops under some sort of shock The two nuclear fragments obtained by the breaking up of the uranium nucleus separate at a high speed (due to the electrostatic repulsion of the two nuclear fragments) yielding a large amount of energy, these fragment nuclei are unstable. They are radioactive and emit electrons and γ-rays by radioactive decay. All these processes yield energy and are part of the total energy released in the process of the fission of uranium This total energy released as gamma rays, beta rays and the motion of the fragment nuclei finally appears as heat This heat is transferred to a cooling fluid which carries the heat of the fission process to the energy transformer which can then be used to operate machines

We have mentioned earlier that Uranium[215] is the most easily fissionable isotope which exists in nature The fission of one gramme of uranium yields as much energy as one could get by burning about 1,000 kilograms of coal The arrangement that Fermi devised for obtaining uranium fission in a chain reaction at a controlled rate of nuclear fission has become a new source of energy which man is using more and more in many countries of the world Since most of the energy of fission appears finally as heat, a nuclear reactor can be compared to a furnace which supplies heat With a nuclear reactor one can devise methods of transferring and using the heat to run machines and generate electric power It is also possible to use it as mechanical power There are ships and submarines built by the United States and Soviet Russia which run on nuclear fission power These ships and submarines contain one or more nuclear reactors which are sources of heat This source of heat is used to heat up the gas which drives the turbines These turbines are connected by a system of gears to the propellers of the ships or submarines The advantage of having a nuclear reactor to move ships or submarines is that coal or oil is not necessary and uranium as a fuel lasts much longer than coal or oil A ship using a nuclear reactor as a source of

energy can travel several hundred thousand miles without refuelling This is because the fission of a gramme of uranium yields as much heat in the nuclear reactor as would be obtained by burning a ton of coal

Nuclear power is now being used to generate electricity in several countries The main advantage is that although the heat value of uranium is up to a million times more than that of coal, uranium is not one million times more expensive, but only about 1,000 times more expensive than coal Since the fuel value of uranium is one million times more than that of coal, the advantage of uranium is roughly 1,000 times that of coal if we consider Uranium[215] alone The advantage is about eight times if we consider natural uranium having both Uranium[215] and Uranium[218]. However, this is not the whole story. Uranium reactors are extremely expensive and difficult to build The machinery for controlling the heat of the reactor and of its transfer to the generating machinery is quite complicated and expensive However, because of its advantages and ultimately cheaper fission power, uranium has a bright future in India and in many other countries There is another aspect Coal is very important for metallurgical purposes (reducing oxides of metals to pure metals) Many Governments now think that coal should be used with care and should not be wasted for producing power where other sources of heat or power are available at a reasonable cost Since the resources of coal are limited in our country, particularly in the southern and western areas, our government has taken steps to make nuclear power gradually available to these areas The first nuclear power station which will generate initially about 400,000 kilowatts of electric power is under construction at Tarapur in Maharashtra This is expected to be finished by 1968 when it will supply electric power to a very large area including Bombay and cities in its neighbourhood The advantage would be that coal will not have to be transported to the areas around Bombay for the running of

UPPER INNER STEEL
THERMAL SHIELDS

UPPER ALUMINIUM
THERMAL SHIELD

RODS HANDLING HOLE

REVOLVING FLOOR

COOLING WATER TRAVELS
DOWN ALUMINIUM TUBES
CONTAINING URANIUM RODS

UPPER
MASTER
PLATE

SHUT-OFF
ROD

UPPER HEADER ROOM

CONCRETE
SHIELDING

AIR COOLED
J-RODS

FOUR BIOLOGICAL
SHIELDS

ALUMINIUM
SHIELD

OUTER
THERMAL
SHIELDS

MATERIAL TO BE
BOMBARDED BY
NEUTRONS IS
INSERTED HERE

SELF-SERVE UNIT
PLACES BALL AT
REQUIRED DISTANCE
FROM CALANDRIA

CAST IRON
SHIELDING

ALUMINIUM TANK
CONTAINING
HEAVY WATER

INSTRUMENT
HOLES

BEAM OF
NEUTRONS
FOR
RESEARCH
EXPERIMENTS

HEAT EXCHANGER

IN

COOLING
SEA
WATER

OUT

CAST IRON
SHIELDING

WHEN BOMBARDMENT
COMPLETED BALL CONTAINING
RADIO ISOTOPE ROLLS OUT
HERE INTO SHIELDED FLASK

WATER COOLED
STEEL SHIELDS

LOWER HEADER ROOM

CONTROL VALVE

GRAPHITE
NEUTRON
REFLECTOR

LOWER ALUMINIUM
THERMAL SHIELD

LOWER STEEL
THERMAL SHIELDS

HEAVY WATER
HEAT EXCHANGER

HEAVY
WATER
STORAGE
TANK

HEAT EXCHANGER

HEAT EXCHANGER

IN

IN

COOLING SEA
WATER

IN

OUT

PUMP

OUT
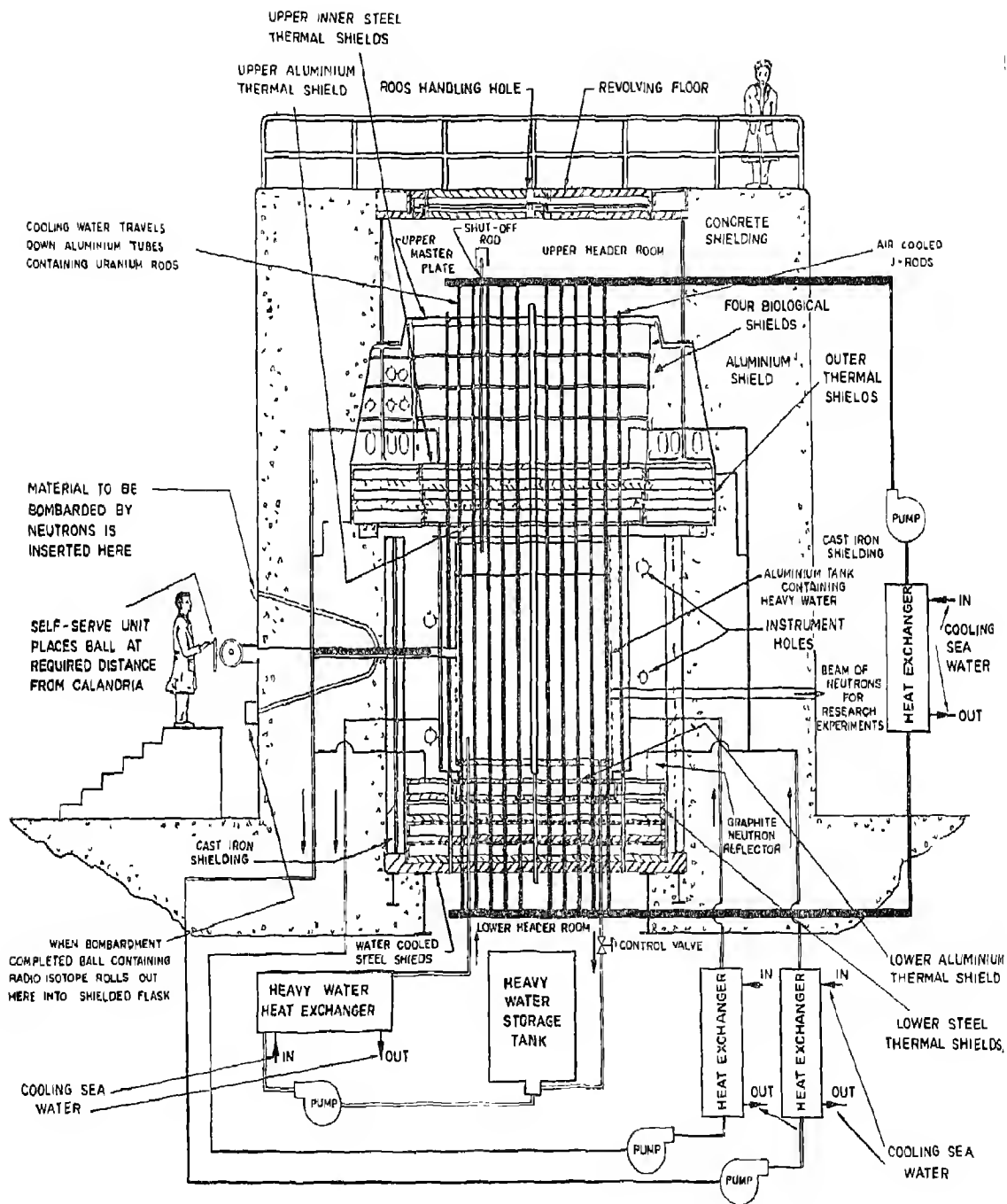
OUT

COOLING SEA
WATER

PUMP

PUMP

PUMP

Fig. 121 Schematic diagram of CIRUS nuclear reactor

machines or power stations A second power station is also being built at Rana Pratapsagar in Rajasthan, this would take a few more years to complete In Rajasthan and in the western parts of our country coal is much more expensive than in the northern areas since it has to be transported to those regions by rail or ship In some southern areas in India even hydroelectric power is not easily and cheaply available, and nuclear power from fission offers the possibility of obtaining comparatively cheap and large amounts of power A nuclear power station is being planned near Pondicherry, this will be the third nuclear power station in India Power is important for the economic well-being of the people. A factory using machines can produce much more goods than a man working with his own bare hands This is possible because machines in a factory use electric power The larger the amount of power available per person, the more would be the goods produced in the country People will get more of the things they need as more power per person becomes available in the country

Since coal and oil production in our country depend on the mining of coal and digging of oil wells as well as on the discovery of new coal and oil fields, it is generally not possible to think of expanding the production of coal and oil infinitely Hydroelectric power depends on the water that falls as rain or snow in the mountainous regions of the country, but there is a ceiling to the amount of hydroelectric power that can be made available by harnessing this water It is, therefore, important for all nations, and particularly for India, to explore the possibility of harnessing nuclear power for their factories In India coal and oil resources are not as extensively and richly distributed as in the U S A or in Soviet Russia It is, therefore, important for India to explore how nuclear power could be obtained cheaply

The fission of uranium is a source of power To be able to use this source of power, a sound understanding of the science and engineering of uranium fission processes is necessary The fission of uranium is a dangerous phenomenon if it is not properly controlled and used with great care When uranium fission takes place the fragment nuclei that are produced are radioactive They emit energy in the form of beta rays or electrons of high speed and gamma rays or X-rays of high penetrating power Both these are a source of danger to human beings and animals, if they are exposed to a large quantity of these radiations

You must have heard of atom bombs. These are also uranium fission devices where in a few kilograms of uranium fission occurs in most of the atoms in about one-millionth of a second The tremendous amount of energy that is suddenly released in the process of an atom bomb explosion as well as the radioactive materials produced in the fission fragments cause a great amount of damage and the death of the people in the area In a nuclear reactor, uranium fission takes place at a controlled rate However, if by any chance the rate of production of fission in the nuclear reactor increases beyond control, the nuclear reactor can also explode It is, therefore, a dangerous device which has to be carefully operated with many precautions Moreover, the nuclear reactor generates a lot of radioactive materials even when it is running under perfect control This radioactive debris, the end-product of the uranium fission process, is a source of potential danger against which many precautions have to be taken

The radioactive fission products are usually removed carefully and stored in such a way that they do not cause any danger to any living being People working in the area have to be carefully protected by many instruments and devices so that they do not run into any undue danger Moreover, in the operation of a nuclear reactor the engineers who operate it do so from a considerable distance with various remote control apparatuses and machinery so that they do not have to come close to the reactor during its operation.

There is another aspect of radioactive atoms Some of the radioactive elements produced in the fission of uranium are very useful, although they are dangerous For example, radioactive iodine is used by doctors and medical men for the diagnosis and treatment of certain types of diseases of the thyroid. Another radioactive element, yttrium, emits gamma rays of low energy which can be used as a substitute for X-rays In fact suitable yttrium sources can be used in many cases for taking X-ray photographs This is a great convenience because an yttrium source is very small and portable while an X-ray machine is not Some of the other radioactive materials produced by uranium fission during the generation of nuclear power can also be put to use All these radioactive elements however, need very careful separation from uranium and other fission products under conditions of considerable danger

There is another kind of nuclear reaction which we have mentioned before This consists of fusion reactions in which the hydrogen nucleus is combined with the nuclei of other light atoms such as lithium, carbon and nitrogen These reactions also release a large amount of energy Some of these reactions are also used in the so-called hydrogen bombs in addition to fissionable materials In the core of a hydrogen bomb there is actually an atom bomb using uranium or plutonium which is exploded first The tremendous amount of energy released by the fission bombs heats up the substances of the fusion bomb to nearly 100,000,000°C so that the atoms of the elements hydrogen and lithium start to move very fast and hit one another at a great speed This causes fusion reactions to occur. More energy is released in the process of reactions which keep the temperature at the level necessary for fusion reactions to continue until most of the elements of the fusion reactions are exhausted

Almost at the very centre of the sun and of the stars the temperature is very high, perhaps several million degrees centigrade Fusion nuclear reactions take place at these high temperatures Almost all the tremendous energy of the sun and the stars comes from these fusion reactions occurring at the centre of these bodies The rate at which the fusion occurs is comparatively slow and the amount of heat and light given out by stars or by the sun is more or less counterbalanced by the amount of energy generated in the interior of the stars due to the fusion reactions This balance enables our sun and most of the stars to maintain almost a constant surface temperature through thousands of millions of years

Scientists have been studying the possibility of producing controlled fusion reactions in the laboratory, this will enable them to generate a large amount of power Since the discovery of the hydrogen bomb, scientists in many countries of the world, particularly in Soviet Russia, United States, England and France, have been studying the many problems connected with the controlled fusion reactions These problems have not yet been solved although some progress has been made in the laboratory Temperatures of over one million degrees have been produced under laboratory conditions. As the scientists learn more of the behaviour of matter at high temperatures, they will be able to solve the problems of producing controlled fusion reactions in the laboratory When these problems are solved and the scientists are able to produce controlled fusion reactions in the laboratory, it would be for the engineers to build fusion reactors and supply electric power as nuclear reactions are doing today In fact, one of the remarkable possibilities of the future is that if man can control and obtain power from fusion reactions, there would be a source of power available to him, much greater than all the coal, oil, electricity and uranium sources that we have in the earth at present.

IX. Waves and particles

If you have observed waves in water or in a string, you will notice that the waves move Float a piece of cork in water The cork will move up and down, staying more or less at

one place although the waves seem to move forward You will notice that apart from the forward movement, there are also crests and troughs, that is, the up-and-down movement of the waves The existence of crests and troughs is the universal characteristic of all wave motion Sound, light, radio waves, heat are all examples of wave motion Sound waves are waves in air, water or some other material Light, heat and radio waves are waves of electric and magnetic fields All wave motions, whether waves in water, air or electromagnetic fields, carry energy It is the energy carried by a wave motion that enables us to detect it. For example, part of the energy carried by the sound waves sets our ear drums vibrating and causes us to recognize or hear sound Similarly the light waves absorbed by the retina of our eye bring about chemical changes on the retina due to the energy they carry These changes are transmitted through the nerves to our brain, causing us to see

Look again at the waves that you generate in a string or in a basin of water, you will notice that there are peaks and hollows and these peaks and hollows follow one another This is characteristic of wave motions and in all wave motions there are successions of crests and hollows or troughs

We can now define the several quantities of waves, which are applicable to all kinds of wave motions Firstly, there is a velocity of wave motion or the speed at which the waves move. We define velocity as the distance in metres through which crests or troughs move in a second The speed or the velocity of the waves is usually a characteristic of the medium and normally remains constant For example, the speed of light in space remains constant and is 3×10^8m per second The speed of sound at sea level, at room temperature and pressure, is about 350 metres per second Sound travels slower in air than in water.

An important quantity in relation to wave motion is the amplitude The amplitude of wave motion is the displacement between the peak and the mean position. For example, the amplitude

of a wave on the sea or in a pond, is the height from the level of the water (when there are no waves) to the peak or crest of the wave The value of the amplitude of electromagnetic waves is the peak of the electromagnetic field strength with respect to the mean electric field (which is zero in free space).

The third important characteristic which describes waves is the wave length The wave length is the distance between two successive peaks or two successive maxima of the electric field in the case of electromagnetic waves Similarly
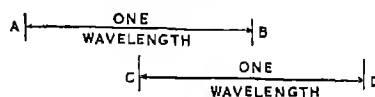
FIG 1 22a *Wave length of a longitudinal wave A, B, are centres of two adjacent regions of compression C, D, are centres of two adjacent regions of rarefaction*
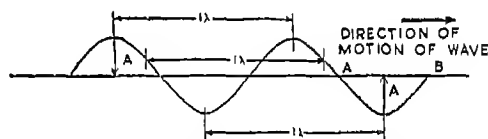
FIG 1 22b *Wave length of a transverse wave All distances marked 1λ are equal and represent the wave length A and B represent points at which particles are moving upward or downward and therefore the distance between them is not the wave length*

the wave length of sound waves is measured as the distance between two successive maxima of compression of air

Frequency is the fourth important quantity in describing the wave motion. It is defined as the number of peaks or crests that pass a given reference point in one second

There is a simple relation between frequency, wave length and velocity for all wave motion—whether sound, light or radio waves or waves in water This relation is given by: frequency × wave length=velocity It has already been mentioned that velocity is measured in metres per second, wave length is also measured in metres and, therefore, frequency is measured as number per second (inverse time) Therefore, if

one knows the wave length and the velocity, one can calculate the frequency, or if one knows the frequency and the velocity, the wave length can be calculated You can use this relationship to calculate the short wave length of a radio broadcasting station if the frequency of the broadcast is given

Stationary waves are a special case of waves which do not seem to move in any direction You can produce stationary waves in a string quite easily You will notice that the stationary
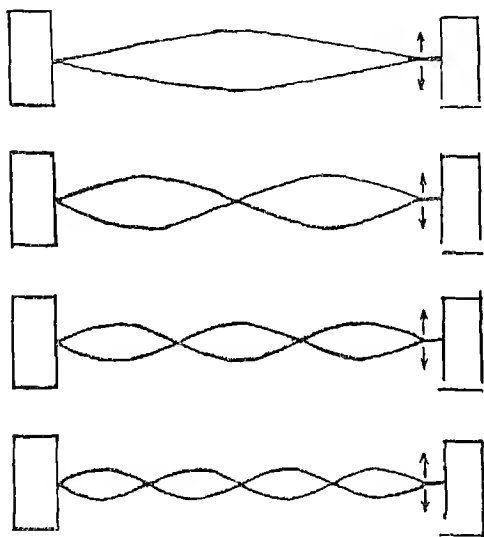
FIG. 1 23   Stationary waves in a string

waves do not move forward or backward The middle of the string rises and falls while the two ends remain stationary The stationary points in these waves are called nodes or points of no motion You can generate stationary waves in a water tank by creating waves which will be reflected from one of the sides of the tank Two waves, viz , incoming waves and reflecting waves, together will form stationary waves in water Stationary waves can also be produced in the case of sound and electromagnetic waves

We say that a wave is transmitted through a substance when it passes through the substance.

Electromagnetic waves such as light or radio-waves may pass through space where there is no matter at all In such cases we say that electromagnetic waves are being transmitted through space Similarly, sound waves are transmitted through air They can also be transmitted through water or a solid substance A wave on the surface of water is transmitted along the surface of water

In transmission through a medium, waves can be partially or wholly absorbed For example, sound waves passing through a wall or light waves passing through a dark glass, such as sun glasses, are partially absorbed In absorption, the amplitude of the wave decreases as the wave travels through matter The decrease in the amplitude of the wave in passing through a medium is often called attenuation Sometimes the thickness or distance of a medium, which reduces the amplitude by $1/e$ of the incident amplitude of the wave, is called the attenuation length of the wave in the medium Darkened glass has a small attenuation length for light waves whereas very transparent glass has a very large attenuation length for light In other words, light is very slightly absorbed by glass The absorption is so slight that it is almost too small to be noticed

Another important aspect of all wave motion is that the velocity of propagation varies from medium to medium This gives rise to the important effect of refraction or change in the direction of propagation of a wave motion when it passes from one medium to another The change in direction is dependent on the ratio of the velocity of propagation in the two media and the angle of incidence, that is, the angle at which the wave motion falls on the surface of the boundary of the two media The ratio of the velocities is called the refractive index

The velocity of propagation of a wave motion in any medium is not usually a constant but varies with the wave length or frequency of the wave motion This effect of variation of the velocity of propagation of a wave motion with the frequency or wave length is called 'disper-

sion' If for any medium this variation of velo-
city with the frequency does not occur, that
medium is called 'non-dispersive' Empty space
is an example of a non-dispersive medium All
electromagnetic waves, of whatever frequency,
whether light, heat, X-rays or radio waves,
travel in free space with the same velocity of
300×10^8m/sec Most media are however dis-
persive, and non-dispersive media are extremely
rare

You are all familiar with the reflection of
light from a polished surface Generally, the
turning back of a wave from the boundary of
two media is called reflection The term 'reflec-
tion co-efficient' is often used to denote the ratio
of the (reflected amplitude)^2 of a wave to the
(incident amplitude)^2 of the same wave Reflec-
tion occurs for all wave motion, sound or
electromagnetic or water waves, at the boundary
of any two media The reflection coefficient
however may be anything from as small as
nearly zero to almost unity

Examine the waves in a water tank If you
start two waves at two places you would notice
that in the region where both the wave motions
occur the amplitudes of the two waves are added
to each other This addition is algebraic, that is
'a crest and a trough tend to cancel each other
while two crests give a higher crest and two
troughs a lower trough' This again is characte-
ristic of all wave motion and is called the law of
addition of amplitudes (or the law of interfer-
ence) We can state the law as follows

Amplitudes of two waves propagating in the
same medium are algebraically added

In water and mercury tanks you can study the
phenomenon of interference The phenomenon
of interference occurs when the amplitudes of
two waves of equal or almost equal wave length
of the same direction of propagation are alge-
braically added An interesting example of
such interference in sound is the beat which
you notice when two strings of almost the same
frequency are plucked together

A very common example of interference is
the colours you see when you put a small drop

of oil in a tank of water and view the reflected
light through the thin film of oil The sunlight
reflected from the air-oil surface and the water-
oil surface interfere with each other while
travelling to your eye Since sunlight contains
many colours or wave lengths, the interference
cuts out one wave length and you see coloured
light which is white light minus the particular
light which has been lost through interference
Since by moving the position of your eye you
can choose various directions at which various
wave lengths will interfere, you can see several
colours Use a fluorescent tube light in the same
experiment and note the dark and bright inter-
ference fringes

We have already mentioned that all wave
motions carry energy This is easily seen when
the wave motion in water produces effects such
as the cork bobbing up and down or in the
vibration of the ear drum when sound falls in
our ear, or when an electromagnetic heat wave
falls on water giving up its energy to heat up the
water The energy carried by waves of a certain
frequency or wave length in a medium is propor-
tional to the square of the amplitude and is
called the intensity of the wave motion The
energy of the waves is measured by taking
waves which are normally incident across a
reference unit area per second

Since waves move with a certain velocity and
carry energy, it is reasonable to ask whether we

can associate a momentum with a wave. For example, a particle in motion having a certain velocity carries with it both a certain energy and a certain momentum ($E=\frac{1}{2}mv^2$ and $K=mv$) Is momentum associated with a wave? The answer is yes A wave also has a momentum
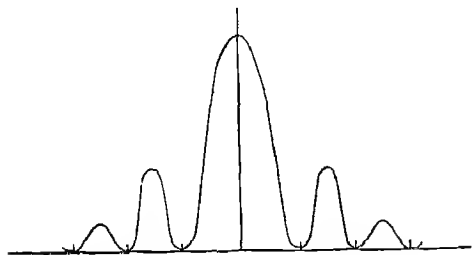

FIG 1 25   *Diffraction pattern of light waves produced by a single slit*

which is given by $K=\dfrac{Energy}{Velocity}$ (of the wave)

This allows us to compare the behaviour of waves and particles In the case of a simple particle of mass M moving with a velocity V, the energy of the particle $E=\frac{1}{2}MV^2$, provided the velocity is small compared to the velocity of light and the momentum $K=MV$. This gives the relation between momentum and energy for matter Compare this to the momentum of waves which is $K(waves)=E/V$

If a particle of mass M travels at a very high speed, that is, its velocity is very near to the velocity of light (3×10^8 metres/sec), then the momentum of the particle becomes not $2E/V$ but close to E/V (or E/c). This property led finally to the discovery that very small particles such as electrons whose mass is 9×10^{-28}gm can behave like waves, as well as like particles This discovery in 1925 proved to be very useful in many ways The wave nature of electrons is made use of in an instrument called the electron microscope which enables one to see objects such as viruses which are too small to be seen under the microscope

All small particles like electrons or protons show this dual nature of behaving like waves as well as particles One consequence of this property is that electromagnetic waves whose momenta are comparable to electron or proton momenta can have collisions with these particles In these collisions, the energy and momenta of both the particles (e.g., electrons) and the waves (e g , X-rays) undergo change These changes take place in such a way that the total energy and momenta of the particle and wave together are conserved The law of conservation of momenta is valid for waves as also for particles

Waves can bend round corners or objects For example, put an iron block in water so that a part of it projects above the water surface, you would see that the water waves bend round the corners of the metal block until finally at some distance from the metal the water waves again join together. This is a common property of all waves (of bending round corners) and is known as diffraction The condition for observing diffraction or the bending of waves is that the object around which bending takes place should have a size comparable to that of the wave length of the wave Diffraction of sound waves can be easily observed by keeping a loud speaker at a distance from an open door and moving slowly parallel to the wall till there is a sudden increase in the intensity of the sound. Notice that you are still in the sound shadow of the wall but sound waves now bend at the edges of the opening and reach your ear Diffraction of light waves can be observed by looking at a flourescent light (tube light) through the thin slit formed by keeping the forefinger and middle finger close to each other As you move your eye across the slit between your fingers you will alternately see thin light and dark bands due to the bending of light waves at the edge of your fingers (See also Figure 1 25)

The Earth

I. Physical parameters of the earth

The earth is one of the nine major planets revolving in the same direction around the sun It takes the earth a year to revolve around the sun and a day to rotate on its axis Its shape is that of a spherical ball slightly flattened at the poles, that is, its equatorial diameter is slightly greater than the polar diameter The volume can be approximated easily by assuming that the earth is truly spherical Assuming that the diameter is roughly 12,740 km , the volume of the earth is nearly $10\ 8 \times 10^{11}$ cubic km The mass of the earth has been calculated to be above 60×10^{21} kg Knowing the mass and volume, the density of the earth is found to be 5 5 kg/litre. The surface rocks have an average density of about 2 7 kg/litre as compared to the over-all average of about 5 5 kg/litre for the earth Obviously the inside of the earth is composed of much denser material than the outer surface on which we live

It is possible to draw an imaginary line through the earth in such a way that the earth rotates about the line as an axis, just as a spinning top rotates around the vertical line through its centre The ends of this imaginary line are arbitrarily called the North and South Poles. The period of rotation is constant and the time taken for a complete rotation is the basis for our day Because of rotation, a point on the equator must travel about 40,000 km in a day, while a point exactly at the North Pole spins in its place, if a point can be said to spin.
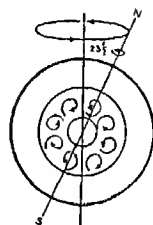
FIG 2 1 *The wobbling motion of the earth The geographical axis of the earth moves in the trajectory indicated by the small circle at the top and completes one full circle in 26,000 years*

The rotational movement is not like the perfect spin of a slow-moving top, the earth wobbles The period of wobbling is quite long —about 26,000 years Thus the earth as a whole rotates, wobbles and, at the same time, revolves around the sun in a nearly circular path lying in a plane Actually the path is an ellipse, and the sun is at one of the foci The distance between the earth and the sun is approximately 149 million km Approximately $366\frac{1}{4}$ rotations take place during a single revolution. Like the period of rotation, the period of revolution is constant, and this defines our year The plane defined by the path or orbit of the earth is a convenient reference. The axis on which the earth spins is inclined to this plane at an angle of $66\frac{1}{2}°$ or, in other words, the plane of the earth's equator intersects the plane of revolution at an angle of $23\frac{1}{2}°$. The speed of the earth around the sun is tremendous in relation to the speeds we are familiar with on the earth. This speed is 29 6 km per second (18 5 miles/second) Since the sun is 149 million km away, the earth's orbit is approximately 928 million km (580 million miles). This distance is traversed

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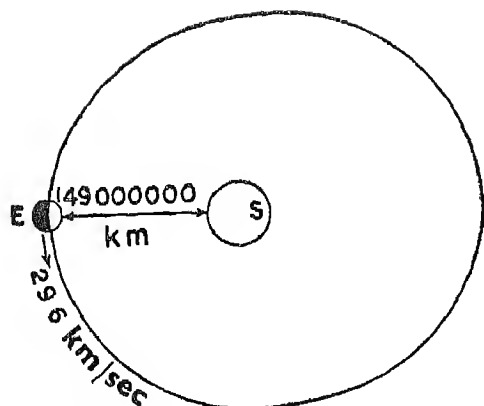
FIG 2 2   *The revolution of the earth round the sun*

by the earth in $365\frac{1}{4}$ or $365\ 25 \times 3600$ seconds, giving a velocity of 29 6 km/sec.

We have so far considered the movement of the earth with reference to the sun Is the sun a stationary body or is it also speeding through space? This can be determined only by considering the position of the sun with reference to the other stars

The earth is one of the nine major planets revolving around the sun It is difficult to cite features that make it remarkable among the nine Perhaps its chief claim is that it is the densest of all Table 2 1 summarizes some of the major features of the sun's family.

All the planets revolve in approximately the same plane as the earth and in the same direction

Figure 2.3 illustrates the relative sizes of the planets If the orbit of Pluto, the outermost planet, is represented by a circle which is a mile in diameter, drawn on a flat field, then the sun could be represented by a ball having a diameter of 8 inches near the centre of the circle, and the earth by a ball of about the size of a ball-bearing shot, 125 feet from the sun

Of all the bodies in our solar system, only the sun produces its own light The surface temperature is about 6000°C and its interior is probably a few million degrees. Its surface is a raging whirlpool of white-hot gases. Because of its self-luminosity the sun is called a star The sun is situated in a spiral galaxy called the Milky Way (Figure 2 4) composed of many millions of stars

The origin of the earth is intimately connected with the origin of the solar system. All the planets of the solar system revolve around the sun in the same direction and nearly in the same plane These dynamical regularities and the physical characteristics of the planets indi-

TABLE 2.1

MAJOR FEATURES OF THE SUN'S FAMILY

Name	The proportional distance from the sun in relation to the sun-earth distance	Period	Diameter (in miles)	Relative mass	Specific gravity	Number of moons
Mercury	0,39	88 days	3,100	0 055	4.8	0
Venus	0 72	255 days	7,700	0 79	4 7	0
Earth	1 0	1 year	7,900	1 00	5 5	1
Mars	1 5	1 8 years	4,200	0 11	4 0	2
Jupiter	5.2	11 9 years	88,000	317	1 2	11
Saturn	9 5	29 5 years	74,000	95	0 7	9
Uranus	19 2	84 years	32,000	14 7	1 3	5
Neptune	30 1	165 years	31,000	17 2	1.6	2
Pluto	39 5	248 years	4,000	0 8	5 0	
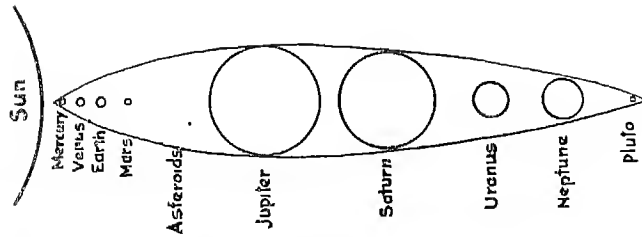
FIG 2 3   *The relative sizes of the members of the solar system*
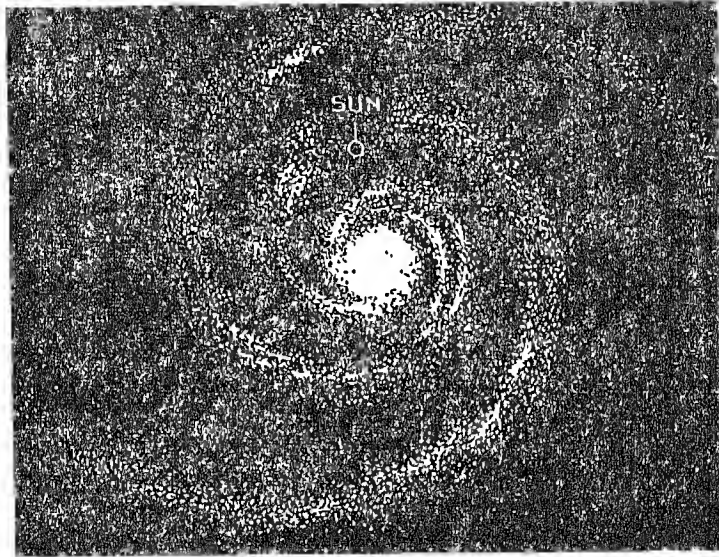
FIG 2 4   *The place of the sun in the Milky Way*

cate that the entire solar system was perhaps created at about the same time by the same process

The Revolution of Satellites and the Rotation of Planets

In recent years there has been a considerable addition to the number of hypotheses proposed to account for the origin of the solar system. None of the theories propounded so far have satisfactorily explained all the important features of the solar system

The various processes that have been suggested for the formation of the solar system can be broadly ascribed to two schools The first one believes in the gradual evolution of the solar

system and the other believes that some sudden and violent action must have given rise to the solar system

The earliest theory was proposed in 1755 by Immanuel Kant, a German philosopher He supposed that the sun was originally at the centre of a nebula (a hot gaseous cloud) that was rotating around the sun under its gravitational attraction. Collisions between the separate particles caused the nebula to flatten out into a disc. The matter in this disc gradually collected round the denser portions, forming a number of planetary systems Kant supposed that in each of these systems a similar evolution took place giving rise to sub-systems

Laplace, who was unaware of Kant's theory,

published his somewhat similar hypothesis in
1796, and for a century it enjoyed unique
popularity He was influenced by two important
factors (*i*) Existence of nebulae in the universe,
(*ii*) The ring system of the planet Saturn

As the basis of his theory Laplace assumed
that far back in time the sun was a great gase-
ous globe with a dense nucleus surrounded by
atmosphere He supposed that the nebula
was rotating, and due to the gravitational
attraction, it contracted, thus speeding up the
rotation When the centrifugal force of the
rotating outer rim exceeded the gravitational
pull of the central region, a ring was thrown off
as mud is thrown off a rotating wheel The
gaseous matter thus thrown off condensed into
planets, Saturn's rings are cited as examples of
rings thrown off but not condensed into satel-
lites These rings of matter, supposed to have
slowly collected into a single aggregation of
gaseous matter, on further condensation and
cooling, developed into planets revolving in
circular or elliptic orbits around the sun Such
shrinkages of the solar nebula and the conse-
quent increased rotation resulted in the forma-
tion of successive planets. An alternative theory
has also been proposed that the planets repre-
sent condensation of matter torn out of the sun
by the gravitational attraction of a passing star
which happened to come close enough to the
sun in its passage However, these various
theories are by no means all the possibilities
We still have no way of saying exactly how the
planets were formed

Relief Features

The major relief features or surface irregu-
larities of the earth are the oceans and conti-
nents About $\frac{3}{4}$th of the global surface is under
water and the rest is land The land is mainly
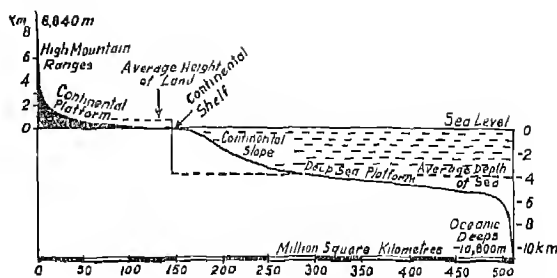
FIG 2 5   *The various typical levels of the earth's
surface from the highest mountain peak to
the greatest ocean depth*

concentrated in the Northern Hemisphere
while the Southern Hemisphere is almost com-
pletely covered by oceans Hence these are
called the land hemisphere and the sea hemi-
sphere, respectively

The continental platform and the ocean plat-
form are the two dominant levels The slope
connecting them includes a submerged outer
border termed as the continental shelf, which
extends beyond the shore zone to an average
depth of 200 metres Figure 2 5 shows the
various typical levels, right from a mountain
peak to the ocean deeps

The continents are broad platforms that rise
steeply from the ocean floors, and have an
average elevation of about half a mile above
the sea level In some places the water is
shallow for a considerable distance from the
shore line, before the descent to the ocean floor
really begins These areas of the continental
shelf are considered a part of the continent, the
implication being that they belong to the conti-
nent, but are just submerged in the sea The
details of the surface features of the continents,
the familiar forms such as mountains, plateaus,
and plains are given below for reference in
classifying borderline cases.

Mountains: Conspicuous elevations with small summit areas

Plateaus   Surface areas that rise above their surroundings and have large,
comparatively flat summit areas

Plains :   Broad regions of low relief that do not rise conspicuously above
their surroundings

The following table gives an idea about the relief

Mount Everest, the greatest known height	8,840 metres above sea level
Sire Deep, the greatest known depth	10,800 metres below sea level
Average height of the land	825 metres above sea level
Average depth of the sea	3,800 metres below sea level

Continental Platform. Most of the continents are characterized by the presence of lofty mountain ranges along one or more of their margins and by extensive plains in the interior The major mountain systems are in two great belts· (*i*) the 'Circumpacific' system is close to the Pacific along the west of North and South America and is much less pronounced along the east of Asia, (*ii*) the 'Alpine-Himalayan' system runs along the southern part of Eurasia The Alps, Himalayas, Urals, Andes and the Cordilleran of N America are conspicuous in the first of these belts The major earthquake and volcanic belts run parallel to these belts

Plateaus are elevated large surface areas, more or less flat, that rise above their surroundings The Deccan Plateau, the S African plateau and the Tibetan Plateau exemplify such features of the earth Plains on the other hand are broad regions of low elevation that do not rise conspicuously above their surroundings

II. The oceans

The oceans constitute the hydrosphere, covering nearly 72 per cent of the surface of this planet

The area of the oceans, including adjacent seas, is 361 million km² The areas of the chief oceans are The Pacific (179 6 million km²), Atlantic (106 5 million km²), Indian (75 million km²) The several marginal seas, bays and gulfs have a total area of 48 million km², of which the Arctic Ocean covers 14 million km² These are included in the areas of the three great oceans given above The total amount of water contained in all the oceans and seas is 1370 million km³ (1400 million km³ according to another estimate)

The northern hemisphere has a larger area of land than of water, while the reverse is the case in the southern hemisphere Land and water are roughly antipodal to each other

The continental margins towards the oceans are of two types· folded, and fractured The Pacific Ocean is surrounded by folded mountains along its entire margin and the mountains are mostly of the Tertiary Age and are thrust towards the ocean The coasts around the other oceans are fractured and faulted, but the structures may be covered in some cases by sediments deposited after the fractures took place The structures on land sometimes terminate abruptly at a coast and their counterpart is occasionally picked up on the opposite coast, this applies particularly to South America and Africa

A section across the oceans shows the following features. Commencing from the shore there is a gently sloping terrace, the *continental shelf* It has an average width of 70 km but varies from 40 km to over 500 km in different places. The total length of the continental shelf, along all the continents, is of the order of 100,000 km and its average slope is 1 540 (i e, about 7 minutes from the horizontal) The average depth at the edge of the shelf is 130 to 150 m, though some authorities put it at 200 m or 100 fathoms The area of the sea floor between the shore and the 100-fathom line is about 28 million km² This is the most important active region of the globe where geological processes are most active and organic life competes fiercely for space

At the edge of the continental shelf the bottom slope increases abruptly to an average of 1 15 (a little less than 4°) and gradually flattens and merges into the abyssal ocean bottom at a depth of around 3000 m There are extensive deep-sea areas, called the *abyssal plains,* at depths of 5000 to 7000 metres which

are exceptionally flat and smooth These lie on either side of the Mid-ocean Ridges which run along the middle of the ocean basin half-way between the continental masses.

The area of the continental shelf is called the *littoral zone* and that of the continental slope and deep ocean, the *benthic zone* As life provinces, the waters over the littoral zone constitute the *neritic province*, and those over the benthic zone, the deep and shallow *pelagic provinces* The neritic and the shallow pelagic provinces are constantly in motion, being influenced by the winds and surface currents As these provinces are amply supplied with oxygen, and well lighted by the sun, they are densely populated by free swimming animals and floating plankton

The features of the ocean bottom are on a grander scale than those on land, but being protected from the forces active on land, they are far more smooth and rounded The mean depths of the three major ocean basins are Pacific, 4282 m; Indian, 3963 m; Atlantic, 3926 m Thus, though the Pacific is larger than either of the other two oceans and contains the great deep trenches, its mean depth is not strikingly different Nearly half of the oceanic area has a depth of about 3900 m, the other half being deeper or shallower The following table shows the percentage of the area between specific depth levels

TABLE 2.2
DEPTHS OF OCEAN AREAS INCLUDING ADJACENT SEAS
(In percentage of the total area of each)

Depth (m)	Atlantic	Pacific	Indian	All oceans
0-200	13 3	5 7	4 2	7 6
200-1000	7 1	3 1	3 1	4 3
1000-2000	5 3	3 9	3 4	4 2
2000-3000	8 8	5 2	7 4	6 8
3000-4000	18 5	18 5	24 0	19 6
4000-5000	25 8	35 2	38.1	33 0
5000-6000	20 6	26 6	19 4	23 6
6000-7000	—	0 2	0 1	—
Over 7000	—	0 2	0 1	—

Corresponding to the mountain chains on land there are several long, narrow, deep trenches in the oceans, particularly in the western part of the Pacific These lie close to the island chains (Island arcs) The maximum depths measured by the Russian Oceanographic vessel, *Vityaz,* in several of these trenches are·

Trench	Depth (m)
Marianas	11,034
Tonga Islands	10,882
Kurile Islands	10,542
Philippines	10,265
Kermadec	10,047
Bonin Islands	9,810
Bougainville	9,140
Yap Islands	8,527
Japan	8,412
New Britain	8,320
Palau Islands	8,138
Chile	8,039
Aleutian Islands	7,679
New Hebrides	7,570

The following are some of the comparative figures for land The mean height of all land is 700 m above sea level More than half the land (56 per cent) lies below 500 m, and half of this again lies below the altitude of 200 metres The highest peaks are in the Himalays and Karakorum, Mount Everest being 8,848 m high If all the land above and below sea level were levelled uniformly to the same spherical surface, the ocean waters would form a layer 2,600 m thick

General Features of Oceans

Submarine topography shows irregularities similar to the mountains, plains, plateaus, basins, etc, present on land The most spectacular feature discovered in the oceans during the last decade is the Mid-ocean Ridge system. This is a great mountain system running continuously along the middle of the Atlantic, Indian and Pacific Oceans The course of the Mid-ocean Ridge is as follows: starting near the

mouth of the Lena River in the Arctic Ocean it runs between Canada on the one side and Siberia and Scandinavia on the other, through Jan Mayer, Iceland, the Azores Plateau, St. Helena, Tristan da Cunha and Bouvet From here it passes between Antarctica and South Africa into the Indian Ocean to Reunion Island It continues northwards as the Carlsberg ridge to the Gulf of Aden From Reunion, the ridge runs to the south and south-east through Macquarie Island and joins the East Pacific Rise (Easter Island) From here one branch runs into the Gulf of California while the main ridge becomes the Mid-Pacific Mountain System, the Tuomotu and Christmas Island archipelagos are parts of this system

In the Atlantic and Indian Oceans, the Ridge is 600 to 1000 km broad, the central zone being mountainous and rugged Along the crest of this zone there is a sunken valley (rift valley) 10 to 30 km wide and over 1000 m deep in places This is marked by volcanoes and shallow focus earthquakes at many places. The top of this ridge generally is within 1500 to 2000 m of the sea level but in several places comes above sea level and forms islands, e.g., Azores, St Helena, Bouvet in the Atlantic, Reunion, New Amsterdam, etc., in the Indian Ocean, Easter Island, Tuomotu, Marshall group, etc., in the Pacific

The abyssal plains, forming the deep, flat, expanses of the ocean bottom, correspond to the plains on land They range in depth from 3500 m to 6000 m They are virtually level and very smooth and cover an area of about 268 km²

Sea mounts and *guyots* occur on the submarine ridges individually and in groups They are conical mountains of volcanic rocks. Guyots are truncated cones of volcanic rocks with level tops Some rise above the sea level but many have their tops 1200 to 1500 m below sea level, showing that their crests were originally above sea level, but were levelled down finally as they sank to their present positions.

Several large faults occur in the ocean floor of the Pacific just west of North and Central America The major ones occur from north to south and are called the Mendocino, Murray, Clarion and Clipperton faults The present steep scarps are over 1 km high. The East Pacific Rise and the Mid-Atlantic Ridges near the equator also show several transverse faults

There are numerous shallower basins along the margins of the oceans Such are the Mediterranean Sea, the North Sea, the Gulf of Mexico, the Black Sea, etc The Caspian Sea was formerly connected with the Mediterranean, while the Baltic Sea was much deeper

The marginal basins are shallower than the oceans and in some cases may have local peculiarities For instance, the Red Sea has high salinity and high surface temperatures because it is hemmed in by deserts The Baltic sea has low salinity, due to the dilution by river waters

A few pit-like depressions and basins have developed peculiar conditions because of their deeper parts being stagnant The lower layers of water in the Black Sea, the Kaoe Bay in Halmahira Island and some of the Norweigian fiords, contain low oxygen or even hydrogen sulphide The Black Sea water contains considerable amounts of hydrogen sulphide (4 to 6 cm³ per litre of water) and the bottom deposits are a sulphurous black mud

The *Island Arcs* constitute a very interesting feature on the ocean margin They are found in front of the continental masses with young mountains thrust towards the ocean There are several of them in the Western Pacific. Those which formerly existed on the western margin of the Americas have been incorporated in the continents The West Indies (Antilles) and Scotia (connecting S America and Antarctica) occur between the continents and are parts of mountain systems which are still in the making

The Island Arcs are thought to indicate a very early stage of continental growth They are segments of circular arcs with a deep narrow trench on the convex side and a line of volcanoes on the concave side. They are located at

the surface of a plane or zone dipping under the continents, along which earthquakes occur at various depths down to nearly 700 km. Volcanic materials rise along these planes and contribute to the growth of the arcs. Some of these island chains are nearly straight, like the Tonga-Kermedec chain, some are broad arcs like the Kuriles and Marianas, some are sharply bent like the Banda Arc (eastern part of the Indonesian Archipelago) and the Scotia Arc (connecting S America and Antarctica)

Properties of Sea Water

The properties of sea water are different from those of fresh water

Colour The colour of sea water depends on the nature and amount of suspended material in it. Clear deep water as that of the Sargasso Sea (Central N. Atlantic) is an intense blue When the water contains a small amount of sediment or plankton, the colour is light blue and blue-green. As the amount of suspended material increases, other colours like brown, red, and yellow are seen The red colour of the Red Sea is due to red algae Diatoms produce a light olive green colour Some algae impart a turbid milky colour. The silt of the great rivers like the Congo, Indus, etc, gives red or brown colour to the water which flows into the sea. The Hwang-Ho contributes yellow mud to the Yellow Sea Most other rivers contribute clayey sediments of a buff (muddy) colour.

Transparency. The transparency of sea water depends on the amount of suspended matter. In open oceans, which are far from land, there is very little suspended material and the water has high transparency Near the shores the transparency is poor In clear water 50 per cent of the light is absorbed within a depth of 10 metres while 90 per cent is absorbed by the time it reaches 70 m or so No light penetrates beyond a depth of 300 metres even with the tropical sun overhead.

Temperature. The oceans show a temperature range between − 2°C and 35°C. The surface temperature varies from 0°C near the poles to 30°C at the equator The (nearly) fully enclosed tropical basins may show a maximum temperature of 35° or 36°C (Red Sea, Persian Gulf) A quarter of the ocean surface (i e, in the tropics) has a temperature above 25°C. The average temperature of the ocean surface of all areas is 17° to 18°C.

The water retains the surface temperature till a depth of 20 to 30 m At a depth of 400 m, the temperature in the tropical and semi-temperate seas is 10° to 15°C In all the deep oceans the temperature is between − 2° to + 3°C, mostly very near 0°

Salinity Salinity varies from 33 per cent (parts per thousand) in the north polar area to 36 per cent in the tropical zone. The salinity is reduced by melting ice in the polar area and is increased by evaporation in the tropics Higher values are got in the Red Sea due to excessive evaporation.

About 8 major ions or 7 salts make up most of the dissolved salts in sea water.

Parts per thousand

Ions in solution		Salts in solution	
Cl^-	18 98	Na Cl	27 21
Br^-	0 065	$Mg\ Cl_2$	3 81
SO_4^{--}	2.65	$Mg\ SO_4$	1 66
HCO_3^-	0 14	$Ca\ SO_4$	1 26
Mg^{++}	1 27	K_2SO_4	0 86
CA^{++}	0 40	$Ca\ CO_3$	0 12
K^+	0 38	$Mg\ Br_2$	0 18
Na^+	10 56	—	—

The other elements found in very small quantities are:

Parts per million (mg per kg of sea water)

C	28	N	0 7 (to 0 01)
Sr	13	Al	0 5
B	4 6	Rb	0 2
Si	4 0 (to 0 02)	Li	0 1
F	1 4		

P, Ba, I, As, Fe, Mn, Cu, less than 0 1 down to 0 01
Zn, Pb, Cs, U, less than 0 01 down to 0 001
Mo, Th, Ge, Ag, V, La, Ni, Yt, less than 0.001 down to 0 0001
Se, Hg, Au (0 000006) Ra, Cd, Cr, Co, Sn, etc , less than 0 00005

Density The average density of the surface of sea water varies from 1 022 in the tropics to 1 028 in the polar region Sea water goes on cooling and increasing in density right down to the freezing temperature, a few degrees below zero Sea water may begin to crystallize at $-2°C$ or slightly below The crystallizing ice expels the salts in solution which increase the salinity of the neighbouring water Though polar surface waters may have a temperature of $-2°$ to $-3°C$, the bottom waters in the abyssal depths of the oceans have a temperature mostly between $-1°C$ and $+2°C$

Movement of Water. Currents

Currents in the sea are produced by the differences in salinity (density), by winds and by alterations in the atmospheric pressure The currents are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, due to the rapid rotation of the earth on its axis

A wind with a constant velocity acting on a mass of water produces a current The velocity of the current and its amplitude depend on the velocity of the wind The current becomes rapidly weaker in the deeper regions At a depth of 200 m its velocity is barely 4 per cent of that at the surface and its direction is at a large angle to the surface current. In shallow seas near the coast the current is practically in the wind direction and is also influenced by the configuration of the coast

Warm tropical waters expand and flow towards the poles In the tropical Atlantic, north of the equator, the current flows towards the Gulf of Mexico Therefrom the Gulf Stream flows north and north-east and turns east near Newfoundland, flowing by the British Isles and then along the Norwegian coast The surface velocity varies from 1 5 to 2 m per sec and may occasionally attain 3 m per sec The current splits some distance south-west of the British Isles and the southern branch flows along West African coast, finally merging with the equatorial current

A cold current flows from the Arctic, alongside Greenland to the Labrador coast where it meets the Gulf Stream There is a lot of mist and fog in the area where the currents meet.

Cold currents from the Antarctic seas flow far north into the temperate zone of the Pacific, Indian and Atlantic Oceans where they rise to the surface Antarctic waters are believed to fill all the deep ocean basins

There are surface current systems in each of the three great oceans There are also deeper currents, particularly in the lower latitudes, flowing in a direction opposite to that of the surface currents The water transported by some of the currents is (in million km^3 per second): Gulf Stream off N America—90, Kuroshio current off Japan—20, N Pacific current from Japan to N America—40, circumpolar Antarctic current—100

Ocean currents transport enormous quantities of plankton which serve as food to the marine animals They also bring dissolved oxygen to the deeper waters The deeper currents are denser than the surface currents Currents play a very important part in the water circulation, salinity and distribution of life in the marginal seas Two or three examples are given below.

The Mediterranean Sea

Though this occupies a large area of over 2 million km^2 it has virtually only one outlet at the Straits of Gibraltar

It is connected on the east with the Black Sea and the Red Sea, and is hemmed in by land, of which the southern portion is mainly a desert Evaporation of water far exceeds the supply by rain and rivers, by about 3000 km^3 per year Water level in the western Mediterranean is 15 to 30 cm below that of the adjacent parts of the Atlantic As a result, at the surface there is a powerful flow of water from the Atlantic, at a velocity of 4 km/hour. The Rocky Will in the Straits of Gibraltar is at a depth of only 400 m The salinity of the Mediterranean is 38 to 39 parts per thousand

6

and this is maintained by an outflow of water, just above the sill The Mediterranean water has been detected in the Atlantic at depths of 400 to 1000 m and for a distance of 200 to 300 km from Gibraltar, beyond which it becomes completely mixed with the less saline Atlantic water The water budget of the Mediterranean is roughly as below.

Gains (km³/year)		Losses (km³/year)	
Inflow from the Atlantic	54,000	Outflow to the Atlantic	52,000
Inflow from the Black Sea	400	Outflow to the Black Sea	200
Precipitation (rain)	1,000	Evaporation	3,400
River inflow	200		
	55,600		55,600

The salinity of the Mediterranean does not increase because the balance is kept by the inflow and the waters are well mixed by the currents and tides.

The Black Sea

The Black Sea is connected with the Mediterranean through the Bosporus which is a very restricted channel. The precipitation here is in excess of evaporation and therefore the outflow is more than the inflow from the Mediterranean As the surface water is of low salinity, it does not sink and therefore the deep basin, especially below 150 m, is stagnant. Light, low-salinity water flows out to the Mediterranean at a mean velocity of 4 km/hour The inflow from the Mediterranean at the bottom of the channel reaches a velocity of 7 to 8 km/hour in the narrow part The salinity of the outflow is 18 per cent while that of the inflow is 38 per cent.

The oxygen content of the Black Sea diminishes rapidly below a depth of 50 m The H_2S appears and increases in the deeper parts to around 4 cm³/litre, reaching a maximum of 6 cm³/litre at the bottom (2000 m). There is no life below 100 m except the anaerobic bacteria including sulphur bacteria. The soft parts of animals are decomposed and the hard parts sink to the bottom and are preserved The deposits are dark green to black, and rich in organic matter and sulphur

The Red Sea

Full data about this sea are still lacking, but will soon be available as a result of the work of the ships engaged in the current Indian Ocean Expedition. This basin is 1800 km long (12° to 30°N latitude) and 270 km wide The bottom which is at a depth of 700 km is irregular. In the north-west, the Red Sea is connected to the Mediterranean through the Bitter Lakes and the Suez Canal In the south-east are the straits of Babel Mandeb, connecting it with the Gulf of Aden and the Arabian Sea Just inside the straits is a sill of rock at a depth of only 100 m. Recent observations show that there are some hot springs at the bottom, especially on the north-eastern side

From November to March, winds blow from the NNW and bring in the water to the south. From April to October there is only a feeble NNW wind in the northern part, but a SSE wind blows from the Arabian sea The two winds meet at about a latitude of 20° N and produce the eddy and the transverse currents. The surface temperature of the water is around 30°C, but it diminishes in winter to 18°C in the northern half The deeper waters have a more or less uniform temperature of 21° to 22°C and a salinity of 40 to 41 per cent

The exchange of water through the Suez Canal is negligible but the outflow through it is highly saline (50 to 55 per cent) because the Bitter Lakes are underlain with beds of salt which had been deposited before the canal was cut During the winter, water flows in from the Gulf of Aden on the surface to the extent of 0.58 million m³ per sec, with a simultaneous outflow over the sill of about 4 48 million m³ per sec The intense evaporation from the Red

Sea necessitates this net inflow Though all the facts on the water budget of the Red Sea are not available, the average annual loss by evaporation is represented by a 3 5 m thick layer of water over the whole area

Waves

Winds produce oscillatory movements in water Short surface waves generally have a small amplitude and die out at a small depth Long waves affect the deeper waters, e g , a wave with a wave length of 180 m and surface amplitude of 6 m at the surface has an amplitude of 1 5 m or less at 40 m depth and about 0 5 m at 200 m depth.

Ocean waves do move water masses forward, especially near the surface High short waves transport larger masses of water than low long waves

For a given strength of wind there is a maximum size of wave. The maximum can be attained only if the water depth is 200 m or more, and only gradually, after several hours In strong winds the wave velocity is 1 5 times that of the wind velocity It is also necessary to have sufficient length of free surface ('fetch') for the wave to develop fully

For wind having a velocity of 6 km per hour

Length of free water (fetch)	Maximum height of the wave (amplitude)
(in kilometres)	(in metres)
5	0 9
10	1 4
20	2 0
50	3 1
100	4 2
500	6 2

Swells

Swells are large waves generated by storms or earthquakes which travel outside the area of their generation They are felt as strong, heaving motion Swells develop heights of several metres but do not show sharp crests.

The wave length is often some scores of metres. occasionally 500 to 800 m, with periods from 10 to 30 sec. Two or more systems of large irregular waves are produced by gales and storms in which the winds frequently change in direction and strength. The smaller waves are suppressed and the large waves predominate The latter generally travel far outside the area of storm and are felt as *swells* As they travel, the period of the waves generally increases, while the height diminishes As the long-period swells travel fast, they are felt far away from the source, while the short-period swells and waves are left behind and are soon dissipated

Tsunamis

These are great ocean waves generally created by large landslides, slumping of earth masses in the sea, volcanic eruptions and submarine or coastal earthquakes Tsunamis have large amplitude (5 to 10 metres amplitude is not uncommon) while exceptional heights of 25 to 30 m have been recorded, as in the Krakatoa eruption in 1883 and in some great Chilean and Japanese earthquakes The wave length is of the order of 100 km, with a velocity of 200 m/sec (720 km/hr) After a submarine earthquake in a region, there is first a withdrawal of water, followed after a short period by a great wave which advances on land like a wall of water. Several waves of decreasing amplitude follow, destroying everything on their path

Waves approaching the coast

Waves advancing over a shelving coast are impeded at the bottom The crests become crowded, the front becomes steep and curls over, resulting in breakers

When the depth of water is half the wave length, the bottom of the wave is impeded, while the top advances and the height increases. The front of the wave becomes progressively steeper and the top curls over and breaks into a spray There is a considerable increase in the height of the long-period wave near the coast.

Waves approaching the coast obliquely become parallel to the coast In this case, the side of the wave nearest to the coast first experiences retardation. The wave progressively swerves and breaks practically parallel to the coast This (always) happens, even in an arcuate bay or on both sides of a cape When waves advance obliquely, a long-shore current is developed

Tides

The regular rise and fall of water level in the seas generates waves which are known as tides. They are caused by the attraction excited by the moon and the sun on the earth The mass of the earth is 80 times that of the moon which is at a distance of 240,000 miles (386,000 km) from the earth's centre The centre of gravity of the earth-moon system lies *within the earth* at a distance of about 3000 miles (4800 km) from the centre The moon revolves around this centre of gravity in 27.3 days which is the duration of the lunar month The tidal force at the point where it is maximum, is only 1/9,000,000 of the force of gravitation of the earth

The moon's attractive force is maximum at the point on the surface of the earth lying on the line connecting the earth and the moon This raises the ocean water at that point and along the meridional line marked on the earth's surface by the vertical plane containing the earth-moon line At the other points on the earth's surface the tidal force is oblique

Moreover, as the moon's path is oblique to the equatorial plane of the earth, the tidal force experienced at any point on the earth's surface varies from day to day.

The sun also exerts a tidal pull on the earth Though the sun is of a huge size it is so far away that its effect is only 46 6 per cent of that of the moon, because of the fact that tidal force varies inversely as a third power of the distance When the sun and moon are along the same direction, (i e , during the new moon and full moon) the total force is $1\frac{1}{2}$ times that of the moon; but when the line connecting them with the earth makes a right angle (as at the end of the first and third quarters) the force is reduced to half that of the moon. The maximum and minimum tides produced during the lunar month are called the *spring* and *neap* tides

The tidal effect pulls the ocean water up from its surface at two points, one nearest the moon and the other antipodal to that point As the moon goes round the earth these two bulges travel with it as high tides, so that during the period of one revolution of the moon around the earth (24 hours and 50 minutes) there are two high tides with two low tides in between, though the obliquity of the moon's path produces, in general, one high tide and one low tide per day

Tides are felt in the open ocean as broad swells They attain some dimensions when they approach the coasts or pass through comparatively narrow paths At narrow entrances with funnel-shaped estuaries or gulfs, the massing of the waters and resonance phenomenon (which depend on the period of the waves, velocity and depth of the bottom) may generate high waves, e.g , in the Bristol Channel in England the waves are 10 m, at St Malo and Rance Estuary in France, 12 m, in the Bay of Fundy in Canada, 15 m

Tides are felt in lakes also The range of the tide depends on the length of the lake. east to west, the shape of the basin and the depth of water, as the period of free oscillation of the water can cause intensification or lessening of the tidal effect

Tidal 'bores' occur in rivers which have developed shoals near their mouth These shoals help in building up a wall of water which rushes up the river, causing heavy damage Bores may travel at 5 to 7 m per second. The Severn Estuary in England is noted for its bores The Amazon often develops bores 4 or 5 m high. Occasionally bores are experienced in the Hooghly and the Meghna in India and Pakistan, respectively

Marine Deposits[1]

Most of the deposits found in the oceans are derived from the land areas. Marine animals form important deposits, especially those which build large reefs with their skeletons, (corals, bryozoa, crinoids, molluscs) These deposits are left behind by the dead animals. Free-swimming organisms like algae and foraminifera also form important deposits. A little extraterrestrial matter, i e , meteorites and meteoric 'dust', also contributes to the sediments.

The thickest deposits are of terrestrial origin, viz , sands, clays and calcium carbonate They are found mainly on the continental shelves and to some extent on the slopes

It is of interest that in some deep sea bottoms there are fairly rich deposits of manganese oxide nodules These must have accumulated by the slow precipitation of the manganese content of the sea waters and by segregation from the sediments over long periods These nodules contain also some nickel and cobalt Such manganese nodules and incrustations are also found on the sea mounts and guyots of the Pacific and Atlantic Their dimensions go up to a metre in diameter The nodules are found only on the surface and not in the lower portions of the deep sea deposits

Another interesting fact about the deep sea sediments is that the fossils found in them are not older than the cretaceous Though there is a school of thought which strongly believed that the Atlantic and Indian Oceans were formed only in the Jurassic and Cretaceous periods as a result of the splitting up of the old Gondwana continent and the drifting of its fragments, everyone agrees that the Pacific is an ancient ocean Yet the Pacific has nowhere yielded sediments of the Pre-cretaceous Age It may be that the disruption of Gondwanaland was such a great disturbing event that even the sediments in the Pacific were assimilated by the great outpouring of the basaltic igneous rocks which

now form its bottom The small thickness of the sediments in all the deep oceans indicates that the rate of sedimentation is exceedingly slow, barely one to two cm per century

Of the four great divisions of the plant kingdom—Thallophyta, Bryophyta, Pteridophyta and Spermatophyta, only the first and last are found in the sea The Thallophyta comprise the various groups of algae amongst which the Diatoms and Dinoflagellates are of special importance as food for animals Several species of Spermatophyta (flowering plants) like the eelgrass (Zostera) and Phyllospadix also have a marine habitat.

Of the animal groups all phyla of the invertebrates and many of the vertebrates excluding the reptiles and birds are found in the sea Even amongst these, land animals depend on marine and fresh water organisms for their food as will be realized from the fact that an enormous number of birds live near the sea or on islands

The protozoa comprise thousands of species and some of them have contributed to the thick deposits in the sea (Globigerina and related genera, Radiolaria) The sponges (Porifera) form colonies attached to the rocks Coelenterata include the Hydrozoa (Medusae), Anthozoa (corals and anemones), various groups of worms, Bryozoa (forming matted tufts and boards), Arthropods, Ostracods, Cirripedes, Copepods and many Crustacea like crabs, lobsters, shrimps, etc), Mollusca (numerous spiral-shelled animals, oysters, clams, shell fish, squids), Echinoderms (sea cucumbers, sea stars, sea urchins, criboids etc) Amongst the vertebrates, the fishes, sharks and lampreys are of overwhelming importance The mammals are represented by several animals like whales, sea lions, sea cows, walruses, etc

Marine life may be divided into three groups according to environment, namely benthos, nekton and plankton Benthos are deep sea and bottom dwellers which may be *sessile* with limited movement (sponges, mussels, oysters, crinoids, corals, bryozoa, etc), or *creeping* on the bottom like crabs, lobsters,

[1] This may be read after the section on The Age of the Earth, on pages 64-66

copeods, snails and some fish, or *burrowing*
like some crustaceans, clams and echinoderms
The nekton are free-swimming animals in the
pelagic zone like squids, whales, fishes, etc
which are thus enabled to travel and migrate
The plankton are quite small floating and
drifting animals and plants, usually buffetted
and shifted about by winds and currents They
are found in enormous numbers and are mainly
the food of other organisms

The Economic Importance of Oceans

It is well known that the climate of the globe
is controlled by the oceans Cheap transport
over ocean waters is an important factor in the
commerce and trade of the world

The oceans are an inexhaustible source of
food and chemicals for man, assuming that the
food supply is carefully managed and not over-
harvested thoughtlessly

Seaweeds are useful as food material, as
manure and as a source of certain chemicals,
particularly iodine

The oceans provide large quantities of nutri-
tious food to man, particularly various fishes,
crustacea and other animals In order to make
the oceans a perennial source of food, much
work is being done in studying the life history
and other characteristics of these animals so that
harmful practices which may reduce or destroy
these sources can be avoided The study of
fisheries on a scientific basis is now vigorously
carried on in many countries and regulations for
controlling fishing are adopted

Fish bones (fish meal) is a rich source of
phosphorous in agriculture Whale oil and fish
oil are used for various purposes Sponge skele-
tons are used as 'sponge', and pearls got from
the oysters are worn as ornaments

Vast deposits of limestones which we now
exploit from the sedimentary strata, are of
marine origin These include limestones com-
posed wholly or partly of corals, bryozoa,
crinoids, algae, formanifera, etc, besides the
chemically precipitated limestones. Most phos-
phate rock deposits (phosphorites) are also of
marine origin Deposits of diatoms and radio-
laria are used as abrasive material, as also flint
which is usually associated with chalk deposits

The materials called 'evaporites' contain
massive deposits of rock salt (NaCl) and also
other salts of sodium, potassium and magnesium,
including gypsum and anhydrite The potash
salts are especially in demand as fertilizers
Some deposits are sources of boron Some
marine sediments are sources of sulphur, as on
the Gulf coast of the U S A and in the Amjhoi
deposits of Bihar. All the petroleum we now
get is from marine sediments, concentrated in
pools by nature

Much of the world's common salt is now got
by evaporating sea water in salt pans Modern
salt works recover other salts and bromine For
over two decades now magnesium (metal) is
manufactured from sea water With the aid of
modern technology many other elements and
compounds present in sea water can be recover-
ed when the necessity arises

III. Hydrology

Hydrology (hydro + logy) is the science that
is related to water It is concerned with the
occurrence of water in the earth, its physical and
chemical relations with the rest of the earth and
its relation to the life on the earth Although
geysers and hot springs can be thought of as a
part of hydrology the central concept of the
science of hydrology is the so-called 'hydrologic
cycle', a convenient term to denote the circula-
tion of the water from the sea, through the
atmosphere to the land and back to the sea
The science of hydrology is especially concerned
with the second phase of this cycle, i e, with
water in its course from the time it has preci-
pitated upon the land until it is despatched into
the sea or returned to the atmosphere Fig 2 6
shows the hydrologic cycle In its broadest sense
hydrology is related to all the waters of the earth,
but for practical reasons it has been limited in
several respects The greatest reservoir of water
on the earth is the ocean, the study of which is
oceanography The study of water in the inter-

slices of the rocks and even the water at comparatively great depths below the land surface belongs unquestionably to the science of hydrology Ground-water studies is one portion of the earth's water circulatory system known as the hydrologic cycle Practically all ground water originates as precipitation (rain or snow) and is maintained by precipitation, stream flow, lakes, reservoirs, excess irrigation, and canals. The hydrologic cycle may be said to be determined by the following conditions

1 The nature and application of the energy that keeps the circulation

2 The inherent properties of the medium of circulation, i.e , of water

3 The structure of the natural reservoirs and conduits

The chief practical significance of the hydrologic cycle lies in the fact that it is the process by which water supplies are furnished to the land, plants, animals and man The fact that water has solvent, evaporative and other properties makes it essential to the life process of all plants and animals, it is adopted for many domestic and industrial uses by man The advancing human civilization has found water to be the most convenient substance for a

large and ever enlarging list of uses. Water that occurs below the surface of the land is invisible and relatively inaccessible and has consequently always possessed an aspect of mystery

Surface Water Out of the total surface area of the globe (5,10,101,000 sq km) about 29 2 per cent consists of land above sea level. The land is very unevenly distributed, in the northern hemisphere there is twice as much land as in the southern Within the northern hemisphere again, the greatest stretch is found between latitudes of 15° and 65° Water on the surface of the earth occurs in the form of seas, lakes or ponds, rivers and ice sheets The mean annual precipitation on the land area is about 100 km. This represents about 140 km^3 of water. Each year, on an average the rivers return to the sea about 25,000 km^3 of water or about 20 per cent of the annual precipitation We can define run-off as the part of the precipitation that appears in the surface streams The run-off consists of two parts: (*a*) surface run-off—that which has flowed over the surface and (*b*) ground-water run-off—that which has travelled underground before reaching a stream All streams return to the sea Through the process of evaporation, some of the water is carried by the atmosphere over the land, and precipitated there as rain and snow. Such changes have been taking place from a long time and it seems they would continue for ever The proportion contributed to the run-off depends on several factors such as the surface slope, permeability of the local rocks, the character and amount of vegetation, temperature and humidity of the atmosphere and amount and distribution of the precipitation throughout the year Therefore the run-off varies greatly from place to place It is said that about 1/3 of the world's precipitation becomes run-off Much of this water streams seaward from altitudes of thousands of metres The energy that results is tremendous. The velocity of the flow and cross-section area of the channel determines the might of a stream Hydraulic action, abrasion, solution and transport together
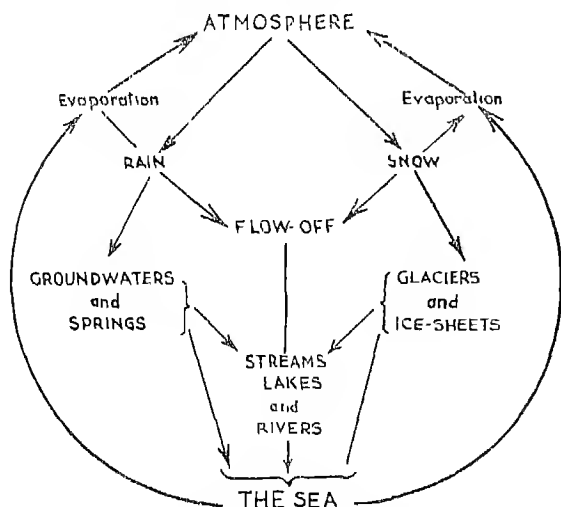

Fig 2 6 *The hydrologic cycle*

constitute stream erosion, and deposition is closely related to all of them Streams are responsible for cutting and deepening their valleys and for transporting the eroded matter from one place to the other They shape the greater part of the land surface including most of the side slopes of the valleys themselves Running water is one of the most important agents of erosion on the face of the earth The present scenery that we see on the surface of the earth is only the latest phase of the ever changing world

Given any river basin under specific climatic conditions, we can forsee the general sequence of events that will take place and thus construct and predict the future by a study of the present The organization of our knowledge about the work of streams in the continuous change as represented by the cycle concept (weathering, transportation and deposition) is an invaluable aid in the study of the sculpture of land by streams

The total amount of sea water is estimated at 1,370 million km³ (about 350,000,000 cu miles) Water stored in rocks below the earth's surface may be about 27 million km³ (6 6 cu miles). This directly or indirectly accounts for the water available for man's use in the habitable parts of the earth But man is directly dependent on the water that falls on land as rain and snow and on underground water (ground-water) The rainfall depends on the evaporation from sea, atmospheric circulation, distribution of land and sea and other factors A comparison of the evaporation from the land with that of the rainfall and snowfall on the land reveals the following figures

Evaporation from		*Precipitation on*	
Oceans	221,010 km³	Oceans	124,441 km³
Lakes, etc	1,576 km³	Land as rain	99,675 km³
Snow and ice	25,220 km³	Land as snow	23,690 km³
	247,806 km³		347,806 km³

A lake is an inland bed of standing water Generally the water is stationary but may have a mild current throughout Lakes always occur where the surface drainage is obstructed. Two necessary conditions are basin-like depressions and sufficient water for the formation of lakes Lakes may consist of either fresh or salt water Lakes vary in size from tiny ponds to bodies of water covering many thousands of square kilometres, although probably more than a dozen in the world occupy areas of about 26,000 km Largest of all is the Caspian Sea with an area of 499,500 sq km Lakes are known to vary in depth from a few inches to a maximum of 1,700 metres, which is the depth of Lake Baikal in Siberia The Caspian Sea has a depth of at least 160 metres Most lakes lie above sea level and a remarkable case is Lake Titicaca in South America (which has an area of 83,000 sq km and is at an altitude of 4,180 metres) The surfaces of some of the large lakes lie below the sea level, examples being the Dead Sea of Palestine (313 metres) and the Caspian Sea (25 metres) The terms 'sea' and 'ocean' are practically synonymous and refer to the whole continuous body of salt water, including its numerous embayments, which covers a large part of the earth's surface

The oceans are very large bodies of deep sea water occupying the basins between continents Thus we have the Atlantic, Pacific, Indian, Arctic, and Antarctic oceans whose average depth is about 4 km The deep seas such as the Atlantic and Pacific oceans are geologically very old, and they have probably remained in the same positions for hundreds of millions of years It is well known that waters of the sea cover nearly 3/4 of the surface of the earth

The land and sea are very unevenly distributed The sea is about 100 times as large as India The average depth of the oceans is about 4 km The Pacific is the deepest of the oceans The deepest sounding ever made was 10,750 metres or more than 9 6 km, in the Southern Philippine Islands

Glaciers A large proportion of the total

volume of water, that is distributed over the land areas of the earth at present, is locked up in glaciers, ice caps and ice sheets. So enormous is the volume of ice that if it were all released by melting and returned to the oceans, the oceans would rise by 50 metres above their present level and submerge all the great sea ports of the world and large areas of the fertile valley land. Slow-moving, thick masses of ice are called glaciers. Snow-fields are thinner, almost motionless masses of permanent snow. Glaciers can originate only in areas where the amount of snow accumulated annually is more than that wasted away by melting and other dissipating processes. Millions of square kilometres of earth are covered with glaciers ranging in area from a fraction of a sq km to millions of sq km. The greatest of all the vast ice sheets are the continental glaciers, occupying much of Greenland and of Antarctica. The land of ice in Polar regions may be about 28.7 million km².

Ground-water Water that occurs beneath the land surface is called sub-surface, underground or subterranean water. It can be divided into two parts. The water that occurs in the zone of saturation, from which the springs and wells are supplied, is commonly called ground-water. The water that occurs beneath the land surface and above the zone of saturation is called suspended water. The subsurface occurrence of ground-water may be divided into zones of saturation and aeration. Perhaps the most fundamental concept in ground-water hydrology is that of the interstices of the rocks, the open spaces forming the receptacles and conduits of the ground-water. The rocks differ very widely in the size, shape and arrangement of their interstices and in the aggregate volume of interstitial space, and these differences are of fundamental significance in hydrology.

The porosity of a rock is its property of containing interstices. The two properties of a rock material that most largely determine the behaviour of its contained water and its productiveness as a water-bearing formation are its specific yield and its permeability. Both of these properties are determined by the characteristics of the interstices and the resultant effects of the molecular attractions. The specific yield relates to the storage capacity of the rocks: permeability is related to their capacity to transmit water. The permeable rocks which lie below a certain level are generally saturated with water under hydrostatic pressure. Their interstices are filled with water that is called ground-water. These saturated rocks are said to be in the zone of saturation. The permeable rocks that lie above the zone of saturation may be said to be in the zone of aeration. The upper surface of the zone of saturation in ordinary permeable soil or rock is called the ground-water table or merely water-table (Figure 2.7). Wherever the
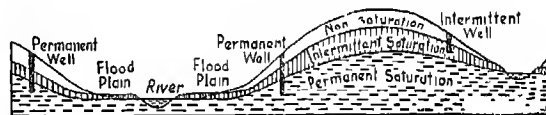
Fig 2.7 *The ground-water table*

upper surface of the zone of saturation is formed by impermeable rocks the water-table is absent. The water-table is very irregular and it is generally farther under the surfaces of hills than of valleys. The water at the higher levels tends to migrate to the lower levels under the action of gravity. Generally the water-table ranges from an inch in depth (from the surface) to 10 or 15 metres. After a prolonged rainfall, the water-table may coincide almost with the earth's surface over a considerable area. Springs, swamps, ponds and lakes are places where the surface of the ground either intercepts, coincides with or passes below the water-table. The water-table lowers steadily during long periods of dry weather and this is why so many wells go dry.

Springs The term spring is applied to sub-surface water which issues from the ground. Springs may be divided, according to their modes of origin, into gravity and artesian springs, and according to the nature of passages traversed by water, into tubular, seepage and

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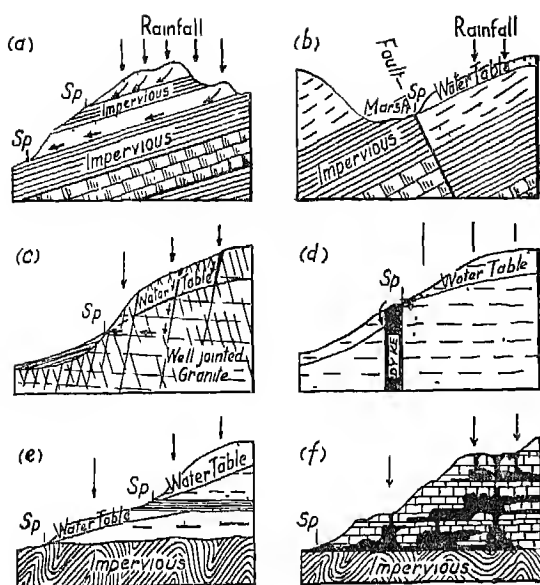FIG 2.8. *Diagram showing the various conditions that give rise to springs*

FIG 2.9 *An artesian well*

15 metres in humid regions When a well sunk to a porous water-bearing layer or formation or crack or fissure (filled with water) encounters water under enough hydrostatic pressure to cause it to rise to a higher level, it is an artesian well (Figure 2 9) Water is often under a tremendous so-called 'pressure head', and it may flow out upon the earth's surface like a fountain
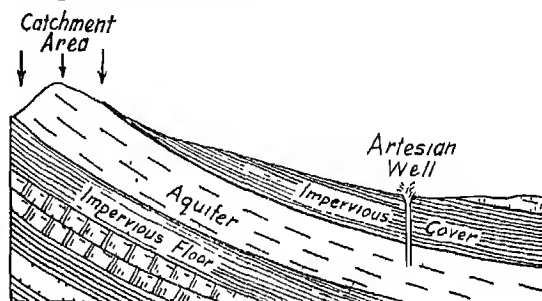
By working on the earth's surface it is sometimes possible to estimate where the ground-water occurs and, under special conditions, to obtain information regarding the quality of the water Investigating ground-water is not easy, nor are the results always successful, however such methods are normally less costly than sub-surface investigations Geophysical methods, developed in the last 30 years for petroleum and mineral exploration, have proved useful for locating and analysing ground-water These are the electrical resistivity and seismograph reflection methods Geological investigation and reconnaissance represent the second approach to the problem The third approach is based on the interpretation of the aerial photographs of the earth's surface. All methods provide only indirect indications of ground-water, as underground hydrological data is inferred from the surface information Correct interpretation requires supplemental data from sub-surface investigations to substantiate the surface findings. Detailed and comprehensive study of conditions under which ground-water occurs can only be made by sub-surface investigations The information concerning the water-bearing strata

fissure springs A gravity spring is one whose water is not confined between impervious beds, but flows from loose materials or open passages under the action of gravity In an artesian spring the water is confined in an impervious channel or (in porous layers) between impervious beds and is under hydrostatic pressure sufficient to make it rise to the surface. Hot springs are those whose temperature ranges from that of the human body to that of the boiling point of water. Geysers are the periodically eruptive hot springs found only in a few of the recent volcanic regions of the world such as Yellowstone Park, Iceland and New Zealand. The water, saturated with mineral matter, emerging at the earth's surface forms the mineral springs which may be cold or hot Mineral springs and wells often yield the so-called hard water which contains a lot of calcite, dolomite, gypsum or certain other mineral salts and solutions If rocks are not homogeneous, the yields of the wells are likely to vary considerably even within short distances Most wells, by far, are simply dug down in loose materials to a little below the water-table The depth seldom exceeds

(its location, thickness, permeability and yield) or ground-water quantitative data (its location, movement, quality) can be obtained from the sub-surface examinations Test drilling furnishes information on the substrata which are in vertical line from the surface. The evolution of these factors aids proper location, construction and development of wells

Air and water are indispensable for living beings From the earliest times human settlements have been established near sources of fresh water such as large rivers and fresh water lakes The need for large quantities of water for industrial purposes has necessitated the scientific study of the sources of water, their development and conservation. There has not been much difficulty in securing the requirements of water from the usual sources of supply During the recent decades considerable amounts of money and engineering resources have been utilized for constructing reservoirs to ensure large supplies of water but this should now be followed by systematic studies of the sources of water-supply Such investigations require full data on the meteorological, geological and hydrological factors in order that the principles of storage of water, its distribution, its movement, etc, are understood properly before the sources can be developed and used to the best advantage

Ground-water is an important source of water-supply throughout the world Its uses in irrigation, industries, municipalities and rural homes continue to increase. Cooling and air-conditioning in the past twenty years have made heavy demands on ground-water because of its characteristic uniformity of temperature Shortages of ground-water in areas of excessive drought emphasize the importance of correct estimates and proper development, and regulation and protection of supplies in order to ensure the continued availability of this key natural resource The largest industrial users of water are oil refineries, paper manufacturers, metal working plants, chemical manufacturers, air-conditioning and refrigerating

units and distilleries. Ground-water use has increased at an accelerating rate in recent years, and indications are that the trend will continue Every country which has embarked upon industrialization is now finding that the usual sources of water relied upon till now are not sufficient and extra supplies will have to be obtained from large distances and from sea or lake water. The consumption of water for drinking purposes alone is of the order of 2 to 8 litres per day per person according to the season, the environment and the nature of work in which the person is engaged Drinking-water is not the most serious problem Requirements for purposes such as agricultural and industrial are much heavier Certain countries which have had to face acute shortage of water have already turned to the ocean for obtaining their supplies Sea water is quite unsuitable for most purposes, but it has been converted into potable water on ships for some decades In recent years, particularly after World War II, the conversion of sea water into fresh water has been taken up for careful study.

Water pollution The quality of water is a primary consideration, whether it is for domestic consumption, for a farm or village or town. So long as the pollution was confined mainly to villages, and agriculture was the major occupation, there was no serious problem of water pollution But the growth of industries, particularly chemical, pharmaceutical, dyeing, etc, has created the problem of disposal of the waste products, some of which are poisonous Similarly municipal sewage disposal is an important problem, sewage has to be treated and made more or less inert before it is allowed to escape into the regional drainage system Where the solid dissolved is largely lime or calcium carbonate, the water becomes hard The degree of hardness depends on the amount of carbonate dissolved Soft water is relatively pure water. However, mineral or inorganic impurities in solution rarely render the water unsafe or dangerous for drinking purposes. The danger comes from organic matter in the sewage, the decaying

vegetable and animal refuse not only impart a disagreeable odour to water but pollute it with dangerous animal and vegetable organisms and render the water bacteriologically unsafe for human consumption Complete examination of water involves a detailed investigation of its physical and bacteriological condition and its chemical character The mere look of water is not a guide to its purity Inorganic matter seldom renders water unsafe for drinking but it may be undesirable for certain industrial purposes Both temporary hardness and permanent hardness should be removed from boiler water since the dissolved matter is deposited as a coating in the boiler.

International Hydrological Decade

Systematic studies of the sources of water supply are necessary to meet the demands of the ever increasing need for large quantities of water for industrial purposes. Such investigations require full data regarding the meteorological and hydrological factors in order that the principles of storage of water, distribution, movement, etc are understood properly Water-supplies are controlled by rainfall, climate, local geography and geology and are liable to vary from time to time The proper understanding of these factors in their local relationship and interdependence will take a fairly long time This fact as well as the size and nature of the problem have suggested that hydrological studies should be undertaken over a period of at least a decade in order that the data collected are reliable The investigations to be carried out include rainfall and its variation over a long period, the influence of local climatic factors, the amount of surface water available, the distribution of ground-water in relation to the local geology and structures, and all other relevant information. This will be followed by a systematic study of hydrological factors and the making of water inventories The development of the resources will require the use of advanced engineering technique which is available only in industrially ad-

vanced nations After the water is used, it will have to be disposed off in such a way that much of it can be utilized again whenever necessary

Hydrology is a very young science, and since water follows no boundaries, this young science has to be studied internationally Numerous observation stations in many nations must be established to study the collection of rainfall, the distribution of surface water, evaporation, absorption by the ground, the flow in rivers, etc The ground-water will have to be examined from the point of view of both the ultimate and actually recoverable resources Tests will have to be made to determine what part of the ground-water can be brought to the surface and utilized without overpumping and spoiling the reservoirs Water is one of the primary resources that the earth has given to man It is unfortunately limited and not all of it can be conveniently used As our knowledge of hydrology increases we expect that better and more economical uses of water for human, industrial, agricultural and hydroelectric purposes will develop.

IV. The interior of the earth

We can observe only the thin outer skin of our planet which has a maximum thickness of a few thousand kilometres Scientists can study the deeper layers right down to 6,400 km beneath the surface This is however done indirectly by studying earthquakes and other phenomena The interior of the earth is a problem which is at once fascinating and baffling. Many books and papers have been published on the subject but there are only a few established facts concerning it The earth's centre is about 6,400 km from the surface whereas the greatest depth so far attained in a deep mine or even in a bore hole is usually much less than 7 km Man has therefore not even scratched the outer layers of the earth, and it will take him a long time to penetrate into the inner regions of the earth in any significant manner. The deepest mines in the world have reached only about 3 3 km and these happen

to be gold mines, e.g., Kolar gold-fields in India, Rand in South Africa, and Morro Velho in Brazil The deepest bore holes have reached 7 5 km below the surface of water (on the Gulf Coast of U S A) where it is almost entirely sediments. In the Pacific Ocean, near the United States a bore hole below the ocean went down to a few kilometres (the Mohole Project) but the project was abandoned when it became very expensive

The mean density of the earth is 5 52 as compared to that of the surface rocks which have a density of less than three A combination of astronomical and geodesic measurements have determined the moment of inertia of the earth about its axis of rotation It was found to be only slightly less than that for a sphere of the same size and mass, with uniform density Therefore, there must be material of higher density near the centre than in the outer parts The American geologist, Dana, and the German geologist, Wiechert, arrived at the model of the earth of a core of high density surrounded by a shell of lower density This model was suggested by the most striking fact concerning meteorites, which are composed chiefly of two different materials, silicates and metallic iron. Wiechert's calculations were based on a central core of uniform density, approximately that of iron, and a rocky shell, with a density approximately that of the heaviest known rocks His subdivision of the interior into two parts, each of uniform density, bears a rough resemblance to the main structural feature, the division between the outer mantle and the inner core. The two densities of the earth found on this assumption as 4 3 and 12 2 are taken as approximately correct.

The temperature goes on increasing as we descend deeper and deeper and can be verified by going down a mine to some depth. Direct observations in deep wells, mines and borings and indirect evidence from the studies of lava in volcanic regions suggest the existence of a temperature gradient in the earth In Europe it has been observed that the temperature
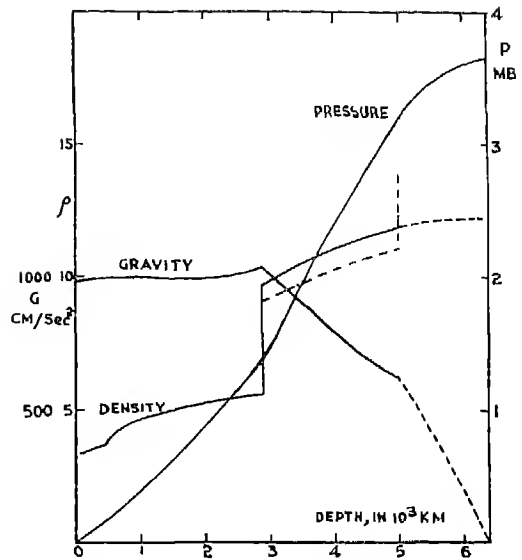

FIG. 2 10   Graph showing the increase of pressure and density and variation of gravity with depth from the surface of the earth

gradient is 1°C per 31 m depth but in North America it is 1°C per 41 m depth. Estimating from the way the temperature rises as we go down, it appears that at a depth of 100 km the temperature will probably be about 900°C If the temperature gradient remains unchanged with depth, it follows that a temperature of 1000°C will be reached at a depth of about 30 km in Europe and at about 41 km in North America. This discrepancy in temperature gradients is attributed to the past geological history of the area Extending the same argument and assuming a uniform temperature gradient, the temperature at the centre of the earth is calculated to be 200,000°C. On the other hand other scientists have put forward the theory that below a certain depth the temperature gradient is reversed and that the temperature at the centre of the earth would not be higher than 10,000°C. Normally at great depths all rocks will be molten. However due to the enormous pressures and temperatures at these depths matter would behave in ways that we do not yet clearly understand

Calculations indicate that at a depth of some

300 km, the pressure inside the earth reaches 100,000 atmospheres, which is about twice the pressure which we expect to find near the centre of the moon. As we approach the centre of the earth, the pressure is expected to reach a figure of 3 million atmospheres Consequently the earth's substances in these regions cannot be considered either as solid or liquid in the usual sense of the terms A litre of average rock weighs about 3 kg. The pressure due to this weight of rock is about 3600 tonnes per sq m At a depth of 40 km, where the temperature (1000°C) is sufficient to fuse all rocks under normal circumstances, the pressure must be around 100,000 tonnes per sq m The core or centre of the earth is probably at a temperature of about 6000°C; it is also under a high pressure —about 30,000,000 tonnes/sq m The effect of temperature is to liquefy rocks and that of pressure is to hinder or prevent liquefaction and keep them solid and compact Hence, at certain depths there is probably the paradoxical condition of a liquid material having many of the properties of a solid owing to the enormous pressures, something like a very viscous plastic solid

The earth behaves like a huge magnet

The earth behaves like a giant magnet with one pole somewhere in north Canada and the other in the Antarctica It is somewhat disconcerting to note that the positions of the poles alter, though to a small extent, from year to year The earth's magnetic field and its characteristics can be measured in any given place These seem to exhibit a complex pattern of variations There

arc hourly, daily, annual as well as long term variations The origin of this magnetic field and the reasons for the variations arc fascinating subjects of study. We are not entirely sure whether the causes of some of these magnetic effects are inside or outside the earth Perhaps both types of reasons contribute to it These arc problems which form an important aspect of the study of the earth The main magnetic field of the earth, however, originates mainly within the earth. No entirely adequate explanation has yet been found, although it is attributed mainly to the interior core of iron However, at the very high temperature and pressure of the core, iron is expected to lose its magnetism It has been suggested that the earth's magnetic field is due to the electric currents circulating within the earth These currents, still not understood by scientists, are probably generated in some way by the motion of the liquid iron core which is electrically conducting

Development of instrumental seismology The development (in 1900) of instruments for measuring and recording the very small movements of the earth have brought out many facts regarding the interior conditions of the earth. An earthquake, no matter where it originates, creates a mechanical disturbance everywhere on the earth. These disturbances travel through the earth A study of the time of their arrival at the various recording stations in different parts of the globe determines the velocity of propagation of the disturbance at various depths of the earth

The outer layer of the earth's surface, to a depth of about 35 km, is often referred to as the crust Below that is an intermediate zone with a thickness of about 2800 km which is referred to as the mantle. Below the mantle and right down to the centre, covering a radius of a little over 3000 km, is the most inaccessible, but scientifically the most interesting region, called the core The crust, the mantle and the core, as detailed above, are the broad subdivisions of the earth's interior and there is considerable evidence in support of such a classification. We
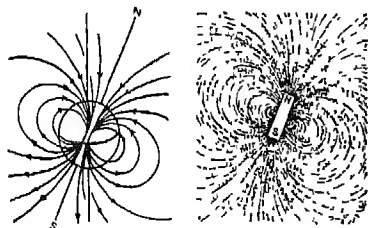

FIG. 2 11   *The earth's external magnetic field, this is equivalent to that of a bar magnet.*
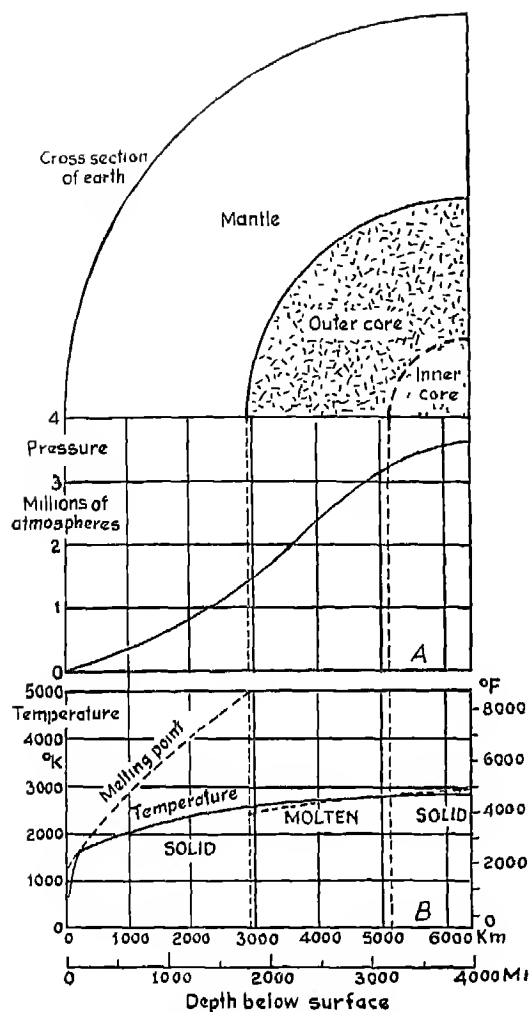
FIG 2 12 *The three broad subdivisions of the earth's interior and the variations of temperature and pressure in each*

shall now enumerate the chief features of each one of these layers

Core The core, as has just been mentioned, extends from the centre to about half the radius of the earth Its mass is a third of the total mass of the earth though its volume is less than a sixth of the total volume Thus the density of matter inside the core should be much higher than the average value of 5 5 kg per litre. It is about 15 kg per litre in the volume surrounding the centre The material is predominantly

metallic and, in fact, largely liquid iron, perhaps alloyed with nickel and some of the lighter elements under great pressures The temperatures in the core are estimated to be a few thousand degrees. There are indications that the core itself may be further subdivided into three distinct subdivisions, the innermost subdivision being iron or other highly compressed matter Experiments show that throughout the crust and the mantle any mechanical disturbance is propagated with two different velocities. The first is the compressional mode, rather like the propagation of sound in a solid or liquid, which travels with a velocity dependent on the pressure and density of the material The second mode is due to a twisting or torsional displacement of rocks and can be compared to the torsional mode or twisting displacement of a rod. The torsional mode travels with a lower velocity than the compressional mode. These two velocities and modes of oscillatory motion are typical of solid matter. The torsional mode does not propagate in the core, but only in the mantle and the crust In an earthquake disturbance, if it passes through a region of the core in its passage to a seismograph, the smaller of the two velocities is not detectable at all There is also a sharp fall in the value of the higher velocity. It is this phenomenon that prompts us to characterize the core as 'liquid' But the nomenclature is probably correct only in a restricted sense An alternative way of describing this would be to say that the core consists of matter in a state which is incapable of exhibiting any rigidity The core, though consisting of iron, as a consequence of the high temperature is non-magnetic Yet it is believed to account for the major magnetic phenomena attributed to the earth, in a rather complicated way, which is not yet understood There is no doubt that information of great scientific value would be discovered if temperatures and pressures that exist in the central regions of the earth could be simulated on the surface inside a laboratory and the behaviour of matter studied under those conditions

Mantle The intermediate zone or the mantle extends from the surface of the 'liquid' core to the bottom of the top crust. Its striking features are the major discontinuities in the velocities of the earthquake waves at its upper and lower boundaries and the existence in it of two distinct and independent kinds of wave propagation with different velocities. Further detailed investigations and comparison of the observed velocities with those found in similar rocks in the laboratories have yielded valuable information about the constituents that make up the mantle and the physical conditions that exist in the mantle at different depths. Three subdivisions of the mantle are detectable although the demarcation between these subdivisions is not so clear as between the principal divisions, namely, the core, the mantle and the crust. One of the important results noticed is that at a depth of about 700 km, which falls within the middle subdivision of the mantle, there is an extreme abnormality in relation to the layers above and below. This is significant as most of the deep focus earthquakes originate at these depths below the earth's surface. In fact all available evidence shows that this region is one of considerable instability.

Crust The demarcation between the base of the crust and the top of the mantle is called the Mohorovicic discontinuity. The relatively thin but complex and easily accessible region of the crust comprises an insignificant fraction of the total volume of the earth. Its volume is about 1/60 of the total volume of the earth. Its mass is less than 1/100 of the total mass of the earth. These figures are, of course, approximate and based on a simplifying assumption that the crust has a uniform thickness and density all over the surface. This, however, is not quite true as the crustal discontinuity between the mantle and the crust is now known to occur at different depths depending on where we measure it, below a plain ground, a high mountain or under the ocean bottom.

At a depth of about 10 km beneath the surface of the sea, the velocity of the faster waves jumps, that is, the compressional wave suddenly increases to about 8 2 km per sec. This is regarded as the line of discontinuity and the beginning of the mantle. On land, an exactly similar jump occurs at a depth of 30 to 40 kilometres and this is identified with the base of the crust, or the Mohorovicic discontinuity. It is difficult to say what happens to the discontinuity as we pass from the ocean to the continent as reliable data of the transitional region, usually termed the continental shelf, are not available. That a 35 km thick crust on land becomes a 10 km thick crust in the ocean is, however, a fact of great scientific interest, which
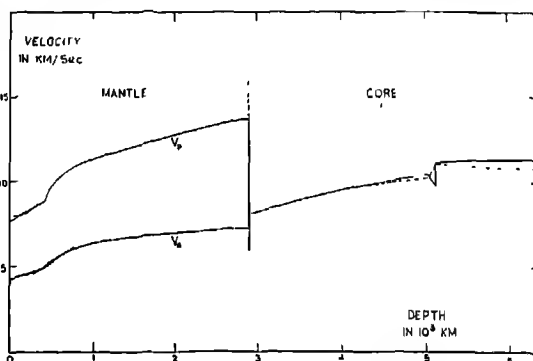
FIG 2 13   *Graph showing the various demarcations of the earth's interior, based on seismic wave velocities*

can only be analysed by a study of the continental shelves separating the oceans from the continents.

The geophysicists are largely agreed that the earth consists of the following zones as given in Table 2 3.

Since all the conclusions are drawn by the interpretation of the data obtained by indirect methods, they are rather speculative and often contradictory. Geophysical data, mainly from seismology, revealed the existence of two major regions within the earth, namely, a dense metallic liquid core of a radius more than one half of that of the whole earth, surrounded by a solid mantle of lower density material, probably olivine (a ferromagnesium silicate) However, the existence of a transitional layer which

TABLE 2.3

Layer		Depth to boundaries (km)	Radius (km)	Fraction of the earth's volume	Mass in 10^{23} kg	Fraction of total mass	Fraction of mass of the mantle
Crust	A	0	6371	0 0155	5	0 007	0 01
		33	6348				
Mantle	B	413	5958	0 1667	62	0 104	0 15
	C	984	5387	0 2131	98	0 164	0 24
	D	2898	3473	0 4428	245	0 410	0 60
Core	E	4982	1389	0.1516 ⎫	188	0 315	
	F	5121	1250	0 0028 ⎬			
				0 0076 ⎭			
Total					598	1 000	1 000

is the seat of important geophysical or geochemical processes does not seem to be disputed. Perhaps the transitional layer is the key to the problem of what is going on in the mantle, and when we understand its nature, we may be able to understand better what is happening in the earth's interior

V. The history of the earth

The scenery we see today on the surface of the earth is only the latest phase of an ever changing world The processes and agents which cause change are the familiar ones of frost, glaciers, rain, rivers, sea, wind and life, including man, their results wear down or build up the surface and thus mould and shape the minor details of the scenery. Man appreciates the geological processes that have gone by during his lifetime and wonders at those which he has not witnessed When we look at a mountain, desert, valley or sea, it seems that they must have always been as they are now We even use such expressions as 'everlasting hills' and 'eternal seas' Actually the earth, including the hills and the seas, is constantly being transformed The process has been going on for at least 3 billion years and may go on for billions of years more Some of the changes like volcanoes and earthquakes that occur on this planet

are sudden and exciting But mostly the changes are slow; it takes 5000 to 10,000 years to make a desert, 100,000 years to cut a small valley and 10,000,000 years to build a mountain range That is how earth uses time. There are places where the sea is creeping over the land Perhaps some day in those places fish and crabs would swim where cities were. As recently as 10,000 years ago great ice sheets covered most of North America and Northern Europe. The ice has now melted and receded back to Greenland and other Arctic regions. The climate will get still warmer

Historical geology is the branch that deals with the sequence of events in the earth's history as interpreted from evidence found in rocks Historical geology includes the records of deposition of sedimentary strata, the geographical distribution of land and sea, the conditions of climate and terrain, and the animals and plants which formerly lived on the continents and in the seas It also includes the dates and places of crustal movements which have from time to time disturbed the pattern of quiet sedimentation—sometimes in very subtle petrogenetic movements, at other times in violent orogenesis which have deformed the strata of geosyncline Historical geology uses many of the methods that are used in archeology or the

study of the early civilizations of man The actual record, whether in the form of rock strata or artefacts or written documents, has to be understood, interpreted and used for inferences The skill of the geologist or the historian lies in reconstructing the hidden meaning of seemingly trivial details In both fields the major problem is the fragmentary nature of the record; an event might have left no record or the record might have been destroyed by some catastrophe in subsequent times The problem of inadequate records generally becomes more serious as the earlier periods of history are considered Early in the 19th century, before geological science was fully established along the lines that it is today, a group of naturalists explained the phenomena of folding and faulting as a result of one or more sudden catastrophes The leader of this school believed that 'the dislocation and overturning of older strata show without any doubt that the causes which brought them into the position which they now occupy, were sudden and violent'. The evidence of these great and terrible events is everywhere and can be clearly seen by anyone who knows how to read the record of rocks. Those who supported this view were known as Catastrophists The tendency of modern geologists is to restrict the geological events of the past by the principle that processes acting in the past have been essentially the same as those seen in action over the face of the earth today It is often summarized in the statement: 'The present holds the key to the past'. Most geologists believe that if they watch a volcano in eruption and see the mountain lava pour down the side of a mountain into the sea, they will be able to explain similar kinds of lava forms now found enclosed in ancient rocks.

Age of rocks and geological formations

Stratigraphical or historical geology has as its aim the description and classification of rocks with a view to arranging them in the chronological order in which they were laid down on the surface of the earth. Of all the three great groups of rocks, sedimentary, igneous and metamorphic, only sedimentary rocks are easily amenable to such an arrangement since they have been deposited layer by layer, together with the remains of organisms which flourished at the time that these sediments were formed The lithological characters and the units which form, particularly their fossil content, have been invaluable for determining the chronology of the material of the earth's crust However, one assumption of geologic formations, that the formation at the bottom is older than the one at the top is a convenient and useful stratigraphic principle. When we deal with several layers, the upper ones are assumed to be successively younger than those below. If the formations have been laid down continuously, each of them grades perfectly into the succeeding one They are then said to be conformable. If there is a break in the continuity, this is called an unconformability or disconformity which is marked by a change in the rock type or by similar features The earth's crust is the scene of constant changes and the rocks are affected by them in various ways They may be tilted, folded and faulted. They may be intruded by igneous rocks or may be metamorphosed as a result of earth movements The final result of these changes, as seen at the present day, is often very complex but the geologists try to observe all the facts carefully and unravel the history of the formations after weighing all the available evidence

The geological formations through such careful studies have been arranged into a few major groups These major groups are divided into systems, each system is subdivided into series and further into stages. Sometimes each stage is divided into zones corresponding to these divisions of formations. The major divisions of geological time are shown in Table 2.4

Of all the sources of information, fossils are the most helpful to the historical geologists These ancient plant and animal remains are impressions preserved in the sedimentary strata, the study of which is known as palaeontology.

TABLE 2.4

Era	Epoch	Age in years	Important rock systems in India and neighbourhood	Distinctive features of plant and animal life	
	Recent	10,000	Recent alluvia, sand dunes and soils	Rise of civilization	AGE OF MAN
	Pleistocene	1,000,000	Older alluvia	Development of man, Extinction of large mammals	
	Pliocene	13,000,000	Siwalik system	Early evolution of man Dominance of elephants, horses and large carnivores	
CENOZOIC (Recent life)	Miocene	25,000,000		Development of whales, bats and monkeys	AGE OF MAMMALS
	Oligocene	36,000,000	Murree and Pegu systems	Rise of primates and anthropoids	
	Eocene	58,000,000		Development of mammals Rise of grasses, cereals and fruits	
	Paleocene	63,000,000		Earliest horses	
	Cretaceous	135,000,000		Extinction of dinosaurs Development of flowering plants	AGE OF REPTILES
MESOZOIC (Middle)	Jurassic	180,000,000	Upper Gondwana	Culmination of dinosaurs The appearance of birds	
	Triassic	230,000,000		First dinosaurs, first primitive mammals, spread of cycads and conifers	
	Permian	280,000,000	Lower Gondwana	Abundance of conifers, development of reptiles and the spread of insects and amphibians	
	Carboniferous	345,000,000		Widespread forest of coal-forming spore-bearing plants First reptiles Abundance of insects.	AGE OF AMPHIBIANS
PALEOZOIC (Ancient life)	Devonian		Mutt Quartzite	First amphibians Many corals Earliest forests spread over lands	

TABLE 2.4 *(Continued)*

Era	Epoch	Age in years	Important rock systems in India and neighbourhood	Distinctive features of plant and animal life	
	Silurian	405,000,000 425,000,000	Silurian of Himalayas	First land plants and air-breathing animals Development of fishes	AGE OF FISHES
	Ordovician		Ordovician of Himalayas	Life only in seas	AGE OF MARINE INVERTEBRATES
	Cambrian	500,000,000	Himanta system	Many marine invertebrates	
		600,000,000			
PROTEROZOIC	Pre-cambrian		Purana formations (Cuddapahs and Vindhyas)	Soft-bodied animals and plants.	
		1500,000,000			
AZOIC	Archaean		Dharwar and Aravali systems	Lifeless	

System of Classification

Formations	Time
Group (e g, Mesozoic)	Era
System (e g, Triassic)	Period
Series (e g, Upper Triassic)	Epoch
Stage (e g, Cainic)	Age
Zone (e g, Tropites)	..

The last 150 years of study have yielded an extremely detailed and nearly complete reference table of the divisions and subdivisions of the geologic time, together with the typical fossils which help to identify the various strata The geologic maps show the location and extent of strata of the different geological ages, using various systems of colour patterns These maps cover almost all the land areas of the earth except those covered by ice caps Geologically speaking, man has come up very recently and risen to a position of dominance over the earth's surface and its living creatures This has happened with almost terrifying suddenness when we consider the tremendous amount of time required for the development of life throughout the Paleozoic, Mesozoic and Cenozoic eras

Physiographical, geological and geographical India has been divided into 3 broad regions The Peninsular Region, Indo-Gangetic alluvium (250,000 sq. miles), and Extra-Peninsular region. More than half of the Peninsula is occupied by the Archaean rocks The Cuddapahs, Vindhyan Gondwanas and the Deccan Traps occupy the rest of the area except parts of the coastal regions In the Extra-Peninsular regions, marine sedimentary systems are pre-

dominant A part of the Himalayas, however, is occupied by the ancient metamorphic rocks The Indo-Gangetic alluvium is composed of sediments and of recent deposits The term Archaean was introduced by Dana in 1872 to designate the formations older than the Cambrian In India the formations below the Eparchaean unconformity, i e , the unconformity at the base of the Cuddapah and equivalent systems are included under the term Archaean Archaean rocks are unfossiliferous and so they were supposed to have formed at a time when conditions for the existence of life were unfavourable For this reason they are referred to as belonging to the Azoic era (era without life) We find, however, that at the beginning of the Cambrian ridge life appears all over the world

The Archaeans form the basement or foundation of the sedimentary system Hence they are referred to as the basement complex The areas in which they occur are called shields (because of their great resistance to the later earth movements which have left them practically unaffected) The Archaean rocks constitute the most important mineral-bearing formations of India The Archaean era was followed by the Purana era during which the Cuddapah and Vindhya systems were deposited in various parts of the Peninsula. Both these systems are practically unfossilifcious though they comprise rocks of considerable thickness eminently suitable for preservation of fossils There is generally a well-marked discordance at the base of the Cambrian strata indicating a period of disturbance and mountain-building In contrast with the Purana formations, the Cambrian formations are rich in fossils After the deposition of Indian rocks and their uplift into land there was a great gap in the stratigraphical history of the Peninsula. At the end of the Paleozoic era, towards the Upper Carboniferous age, a new series of changes took place over the surface of the globe, which brought about a redistribution of the land and sea and was also responsible for the mountain-building
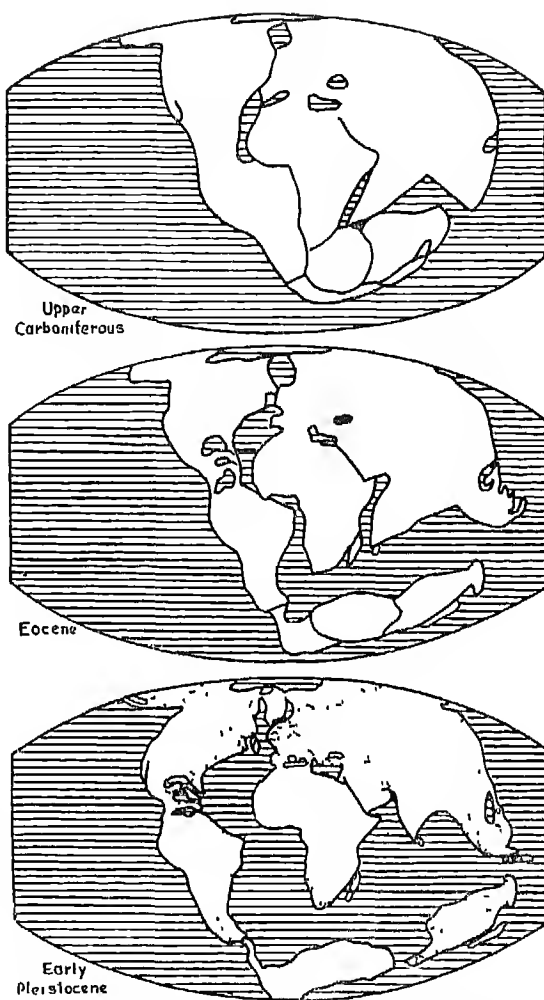

FIG. 2 14. *The clustering of continents (Gondwana land) according to Wegner's hypothesis and their separation by continental drift*

movements. At this time there existed a great southern continent or series of land masses which were connected closely enough to permit a free distribution of terrestrial fauna and flora The southern continent which included India, Australia, South America, Antarctica, South Africa and Madagascar has been called Gondwanaland This era began with a glacial climate for we find the deposits commencing with glacial boulder beds, in all the above-

mentioned lands Fossil deposits trapped in this strata are mostly amphibian and reptilian fauna The widespread fossils of this era are strikingly similar and probably denote large and unrestricted inter-migration of these animals Though the Gondwanas are generally referred to as a system, their extent and magnitude in space and time entitle them to be considered as a major group They comprise strata of a total thickness of about 20,000 to 30,000 ft (6 000 to 10,000 m).

The Triassic system is the earliest of the three systems which make up the Mesozoic or secondary era Amongst the vertebrate fossils of this era, the fishes are quite abundant The close of the Mesozoic era was marked by the outpourings of enormous lava flows which spread over the vast areas of western, central and southern India The area now occupied by these lava flows, in the Deccan traps, is about 500 000 sq km including Bombay, Kathiawar, Kutch, Madhya Pradesh and Central India The traps attained their maximum thickness near the Bombay coast where they are estimated to be well over 2000 m The end of the Cretaceous era was marked by important changes in the fauna and flora The Himalayan mountains had their birth during this period The mountain-building activity continued intermittently throughout the Tertiary era and brought into being the great equatorial mountain systems which include the Atlas, Pyrenees, Alps, Caucasus Himalayas and the Malay Arc The rise of the Himalayas took place in a series of five or more stupendous movements punctuated by intervals of comparative quiescence The final phase of the Himalayan movements took place in the early Pleistocene era when the Pir-Panjal was raised to its present height The Quaternary era was heralded by a general lowering of the temperature of great ice sheets of continental dimensions extending from the north pole to the greater part of Asia, Europe and North America Glaciers in the Himalayas descended to as low an altitude as 5000 ft, as indicated by the presence of moraines and other features

VI. The age of the earth

The age of the earth is still not established with absolute certainty Answers to this fascinating question of the earth's age involve the widely differing techniques of several sciences Speculation and mythology often distort our thinking on the earth's age

Scientists today have accumulated evidence which points to a figure of about 4500 million years One of the modern methods of estimating the age of the earth is to estimate the age of the various rocks found in different regions of the earth and attribute the age of earth to ages comparable to but greater than those of the oldest rocks

The 'age of the earth' can be interpreted in two ways . (i) the period that has elapsed since the earth and the other planets started their independent existence as whirling masses of white-hot gas is perhaps between 5000 to 7000 million years ago, or (ii) the time since the earth's crust solidified and the geological processes began to take place on it (the geological age) that is, since the earth started behaving in a way fairly close to what it is now A third time scale is that of the biologists who have built a history of the earth from the evidence of fossilized living creatures of the past

The 'record of the rocks' is the source book of the geologists It is a very ancient book and, second only to the record of the universe in antiquity, and like all manuscripts that have suffered the vicissitudes of time, it is very fragmentary and difficult to read. The geologists have divided the source book into five sections and later into chapters The table of contents of this book is generally and popularly known as the 'geological time scale'

How old is the earth?

The scientific approach to this problem was first made by geologists as recently as the nineteenth century. In 1898, Joly observed that the rivers carry down to the sea small but measurable amounts of salts every year Joly proposed to use the sodium salts as an index to

earth's age Innumerable surveys and analyses of the principal rivers carried out in all parts of the world show that 156 million tons of sodium in the form of salts are being added annually to the sea Hence, assuming that the addition of salts to the sea is uniform throughout geological time, it was estimated that the age of the oceans cannot be greater than 81 million years Serious objections were raised against this theory by geologists on the grounds that the salt existed in the oceans even at the time of their formation and that the rate of deposition of salt into the sea is not uniform throughout the ages since the seas have not occupied the same positions as they do now Taking into consideration these facts, the estimated sodium carried in solution annually was reduced to about 33 million tons and the corrected age of oceans to about 330 million years This is far too low, judging from other indications that the geologists have found through the years.

Physicists made an approach to this problem by estimating the rate at which the earth cooled down from the very high temperature at the time of its creation to the present relatively low temperature. Assuming that the earth was born out of the sun and that solar temperature has not changed one can estimate that early in this process a solid crust must have been formed. The rate at which the earth has cooled must therefore depend on the rate at which heat is conducted through the earth's crust. Lord Kelvin measured the heat conductivity of some of the typical rocks forming the earth's surface. These various values of conductivity of rocks thus obtained, together with the different estimates of the thickness of the earth's crust at different stages of its history, gave a value between 25 to 40 million years for the time taken by the earth to cool to the present state. These values were in marked contrast with those of Joly and other workers This discrepancy was at once recognized as a serious defect because both biological and geological theories favoured much longer time scales At this time the theory of biological evolution had come into

existence, and biologists had built up a time scale for the various stages of evolution The time sequence for the formation of successive groups of rocks, worked out by biologists with the support of geologists, was much longer than the time allowed by Lord Kelvin for the same purpose The missing factor which caused such a large error in Kelvin's reasoning became apparent after the discovery of radioactivity. Kelvin's mistake was to leave out of account that the earth also had a source of heat released by radioactive transformations occurring in the rocks and minerals This turns out to be substantial. Not only does radioactive heat make Kelvin's method of estimating the age of the earth wrong, it also provides a new and accurate method of measuring geological time.

The French physicist, Becquerel, made the outstanding discovery that uranium salts and minerals give out invisible rays which are capable of penetrating paper and other materials and can blacken photographic plates wrapped in black paper. Madame Curie and Prof. Curie followed up this observation by an exhaustive examination of all the elements then known They were able to discover that certain elements such as uranium which emitted radiations at a constant rate were unaffected by chemical, physical or any other process They also discovered several radioactive elements, amongst them were radium, polonium and thorium. Radium deserves special mention since it is more than a million times (more) radioactive than uranium. Now we know the existence of over thirty or more radioactive elements, all of which are produced by radioactive decay of uranium and thorium Lord Rayleigh revised the calculations of Lord Kelvin by trying to measure correctly the heat produced by the radioactive chemical elements Since he could not estimate the amount of radioactive chemical elements on the earth his correction did not give accurate estimates. However, the constant rate of decay of radioactive elements is the basis of a modern, accurate method of estimating the age of various rocks and minerals which are found in

different regions of the earth Many of these rocks contain small amounts of radioactive elements which have been decaying by emitting radiations of different kinds The ultimate residue of decay of the radioactive elements in the family of uranium and thorium is lead During the process of rock formation the end product, lead, as well as the parent radioactive material often get trapped in the body of the rock If therefore, the amount of uranium, thorium and lead in a rock specimen is measured, one can calculate when the rock came into existence, since the rates of decay for these elements are known. A fairly reliable figure for the age of a given rock can be obtained by this method However, such a determination sets only a lower limit for the age of the formation in question and the limit is valid only until a rock to which we can assign an older age has been found in the same region. Many of the oldest rock specimens from different parts of the world have been studied by this and other similar methods based on the principle of measuring the end products such as lead or letium in the process of radioactive decay. The present indications using those methods are that the oldest rocks are mostly pegmatites (coarse-grained granite) found in some regions of the earth, with a maximum age of about 2700 million years

The figure of 2700 million years, however, is less than what we can regard as the age of the earth The age of the earth will properly be the age at which the earth's crust was formed. Detailed studies by scientists, using differing methods, have been made in respect of the average granitic rocks, a large and old constituent of the earth's crust. The age for the oldest granites is in the neighbourhood of 2500 million years. These methods can be applied to meteorites, the wandering pieces of stone or metals in the solar system that occasionally fall into the earth. The oldest age of the meteorites that recent investigations have shown is about 5,500 million years Since the meteorites as well as the earth are parts of the solar system it is

possible that the earth and meteorites may well have been formed at about the same time Since the oldest pegmatites are 2700 million years old, it is likely that the earth's crust got consolidated another 1500 million years or so earlier, that is about 4500 million years ago The history of the earth during the interval between 4500 and 2700 million years remains unclear, as does the earlier period before 4500 million years ago. Theoretically, 4500 million years should be regarded as a lower limit for the earth's existence. Actually, it is unlikely that the true age of the earth is a great deal more than this figure.

VII. Earthquakes, volcanoes, fumaroles, hot springs and geysers

Earthquakes

Many of you have experienced the sudden shaking of buildings and even the earth, these are earthquakes and they occur quite often. Fortunately, most of them are weak and do not cause serious damage to human beings Once in a while a big earthquake occurs If it occurs in areas where there are human habitations, cities and towns, it causes destruction of human life, buildings and structures. A large earthquake occurring in hills and mountains can change the course of a river or the watershed areas of the region Earthquakes are due to the gigantic forces kilometres deep in the earth's crust which are continually trying to push or pull, bend or stretch, squeeze or twist the compressed interior of hot rocks They are more powerful than any forces, natural or man-made, that we see at work on the surface The underground forces build up for a time, like steam pressure in a boiler For months, years, or even centuries, these forces build up Then, all at once, some weaker part of the underground rock mass reaches its limit of endurance. Under unbearable stress, it cracks or fractures, and the release of stored up forces causes a violent shivering motion in the bedrocks around it An earthquake is what happens when large blocks of the earth's crust slip, slide or break.

Seismology is concerned with certain aspects of earthquake phenomena The tremor or quake is propagated through the elastic rock material of the earth as a wave motion which travels at a speed of about 400 miles a minute The seismograph, ingenious yet simple, is an alert watchman Seismographs are very sensitive The frame is anchored in the bedrock. One end of a pendulum is atached to the frame and the other end which is quite heavy is free. When
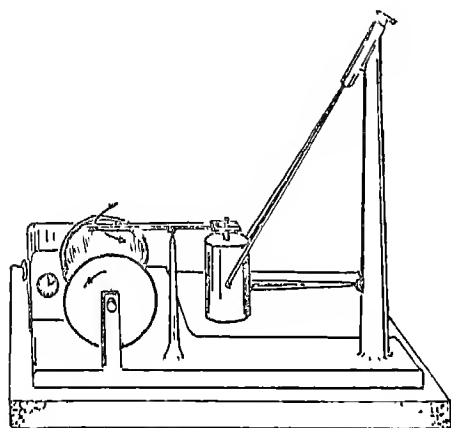

FIG 2 15 *Seismograph*

the earthquake causes the bedrock to shake, the frame shakes with it But the free end of the pendulum remains practically motionless. A rotating spool of photographic or chart paper is built into the frame. A steady beam of light coming from the free end of the pendulum draws a continuous line on the paper as the spool unrolls During the earthquake the bedrock vibrates So does the spool. But the beam of light coming from the practically motionless pendulum does not shake. Consequently, the line it makes on the paper is wavy and the earthquake is recorded The more severe the earthquake, the bigger are the waves in the line. There are on an average several thousand earthquakes per day Most of them are so slight that they can be detected only by seismographs, but about 25 quakes each year are big enough to do serious damage Most earthquakes start

from faults within 60 km or less below the earth's surface Some occur at depths of over 300 km and very few at depths of over 650 km The very deepest ones occur mainly in the Western Pacific region where mountain-building is now rapid and volcanic activities are constant Some earthquakes originate on or close to the ocean floor, especially near the narrow curved deeps or gorges in the ocean floor These submarine earthquakes generate sea waves (the Tsunamis of Japanese seismologists) which can sometimes be quite destructive.

The originating centre of earthquake waves of some volume is called the focus It is usually situated at a depth of only a few miles but can sometimes be much deeper The area on the surface vertically above the focus, where the shock is most intense, is called the epicentre The waves spread in all directions from the focus with gradually diminishing intensity as the distance increases Points of equal intensity of shock, if joined up, will give a series of
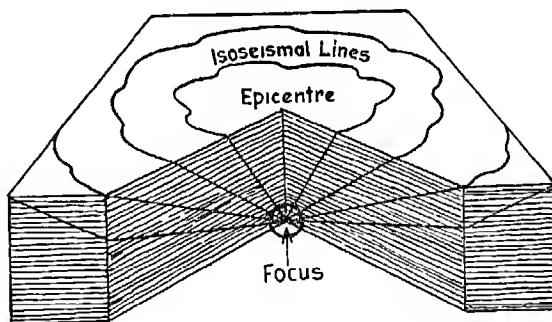

FIG 2.16 *Isoseismal lines, epicentre and focus*

irregular spherical or ellipsoidal surfaces concentric with the focus These shells will intersect the earth's surface in a series of irregular concentric lines around the epicentre. These lines, which join the points of equal intensity of shock on the surface are called isoseismals Earthquakes are mainly produced by sudden shiftings of weight due to earth movements which are, in turn, caused by the growth of folds and faults Earthquakes may also be

9

caused by volcanic outbursts, by rockfalls in great landslides, and by the collapse of the roofs of caves and old mine workings These, while occasionally severe, are usually light and always local in their effects Mild tremors, detectable only by delicate earthquake instruments (seismometers), are caused by relatively small shiftings and accessions of weight such as the diurnal movements of the tides, heavy rainfall and rapid variations of atmospheric pressure Moreover, as the earth is non-uniform and is rotating at a tremendous speed, its crust is constantly trembling like the rim of a badly balanced flywheel

The typical seismograph of an earthquake record shows first a series of undulations (first preliminary tremors) due to the P-waves which travel the fastest, then a series (second preliminary tremors) due to the S-waves, and finally undulations of much greater amplitude (main shock) produced when the slow L-waves arrive
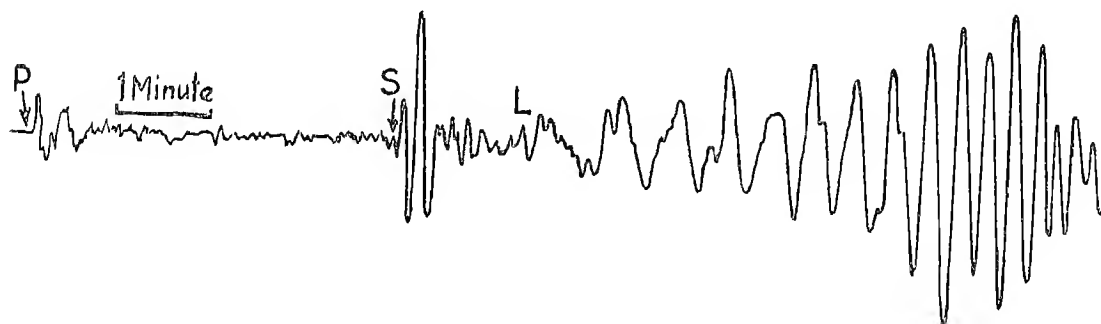
two miles per second. This enables one to locate the epicentre of an earthquake Thus, if a seismograph records P- and S-waves arriving 200 seconds apart, the epicentre is about 100 miles away

Effects of Earthquakes

Apart from the immediate destruction of life and property, earthquakes produce geological effects

Tensional Effects Tensional effects include fissuring and faulting consequent upon the tearing apart of the earth's crust. Visible folding is seen in major earthquakes Extensive fissuring of the ground often accompanies great earthquakes and this interferes with the drainage causing some springs and wells to fail and new springs to appear at other places Large quantities of sand and mud are brought up and strewn over the surface by the water Compressive effects are shown by the contraction of

FIG 2 17 *Seismograph record of an earthquake*

The epicentre of an earthquake, that is, the location on the crust where the shocks are strongest, can be learned from the analysis of the shock waves. These are of two main types. The primary P-waves travel through bedrock like ripples across the surface of a pond The secondary S-waves are more like loops along a rope, shaken at one end, P-waves travel at 5 miles per second, and S-waves at 3 miles per second. When an earthquake occurs, the P-waves always reach the seismograph earlier and the S-waves with a difference in speed of

the earth's crust through earthquakes, attested by the vertical or horizontal buckling on railway or tramway lines and by the telescoping of sewer and water pipes In the Japanese earthquake of 1891, river valleys were narrowed and plots of land compressed from 16 yd in width to 10 yd to the great dismay and indignation of people. Gravitational effects produced by the earthquakes include throwing down of loose materials lying in unstable or near-unstable positions, as landslides.

The material effects of earthquakes on human

cities and structures are so damaging that much thought has been devoted to the possibility of minimizing them by the recognition and avoidance of situations specially liable to earthquakes, and by suitable building designs in earthquake regions

Important Earthquakes. An important consequence of earthquakes to us is the damage they produce One of the worst of all earthquakes hit the cities of Yokohoma and Tokyo in Japan a generation ago These cities lie near the shores of Sagami Bay In September 1923, the bottom of the Bay suddenly sank The whole region took a frightful shaking Before the disaster was over the entire city of Yokohoma was a smoking ruin and half of Tokyo was gone. The damage amounted to hundreds of crores of rupees and 140,000 people died among the fallen buildings and flames In the United States, the most disastrous earthquake was one that shook San Fransisco in 1906 At five in the morning when most of the city was still asleep the tremors began. The wooden buildings caught fire and the city burned for days About 450 people lost their lives When the volcano of Krakatoa blew up in 1883 there was a tremendous earthquake and the resulting wave caused damage at distances up to a thousand kilometres away An earthquake in 1908 in Sicily killed 76,000 people and injured 100,000 persons In the Kansu earthquake of China in 1923 the loss of life was more than 100,000. According to Malley, the world has lost at least 13,000,000 lives in earthquakes in the past 4,000 years According to an estimate, Japan, one of the most earthquake-prone nations of the world, experiences three shocks on the average each day.

Earthquakes in India Earthquakes occur in regions of marked instability of the crust such as mountain belts of recent geological date. One such region is the zone of Himalayas, and the Burmese and Baluchistan Arcs around the northern borders of the Indian Peninsula which have faulted and folded and overthrust during the Tertiary period The peninsular part of India

is a region of high stability as mountain building movements in this area had ceased long ago. The Assam earthquake on June 12, 1897 was one of the most disastrous shocks that ever occurred. Shillong and the neighbouring areas (350,000 sq km) were almost completely destroyed within a minute The North Bihar earthquake on January 15, 1934 was another huge earthquake in which more than 12,000 people were killed The Quetta earthquake on May 31, 1935, killed nearly 20,000 people A recent disastrous earthquake was that of August 15, 1950, near Rima (29° N 97° E in the Zayal Valley on the Assam-China border in front of the Assam wedge). Fortunately the shock occured in sparsely populated areas Eyewitness accounts state that during the Assam earthquake of August 15, 1950, the earth began to shudder violently, solid-looking hills seemed to be in the grip of a force which shook them as a terrier shakes a rat. Mountains were badly mauled, wide belts were ripped off, carrying trees and rocks with them The general destruction was terrible and widespread In fact the total energy released during the Assam earthquake has been estimated to be of the order of 10^{27} calories which is equivalent of the energy released by the simultaneous explosions of a million atom bombs of the usual variety or of over a thousand hydrogen bombs The Assam earthquake has been reckoned as one amongst the five or six big ones that have occurred during the whole of human history.

The greatest belt of seismic activity is round the border of the Pacific and affects Alaska, Aleutian islands, Kurile islands, Japan, the Philippines and Solomon islands, New Guinea, New Zealand and the west coast of the American continents A second and less important belt includes the Mediterranean region and passes through Asia to join the Pacific belts in the East Indies There are lesser belts in the Arctic, Atlantic and Indian Oceans and in East Africa A study of earthquakes during the last 150 years shows that they have occurred all along the Himalayan, Burmese, Balu-
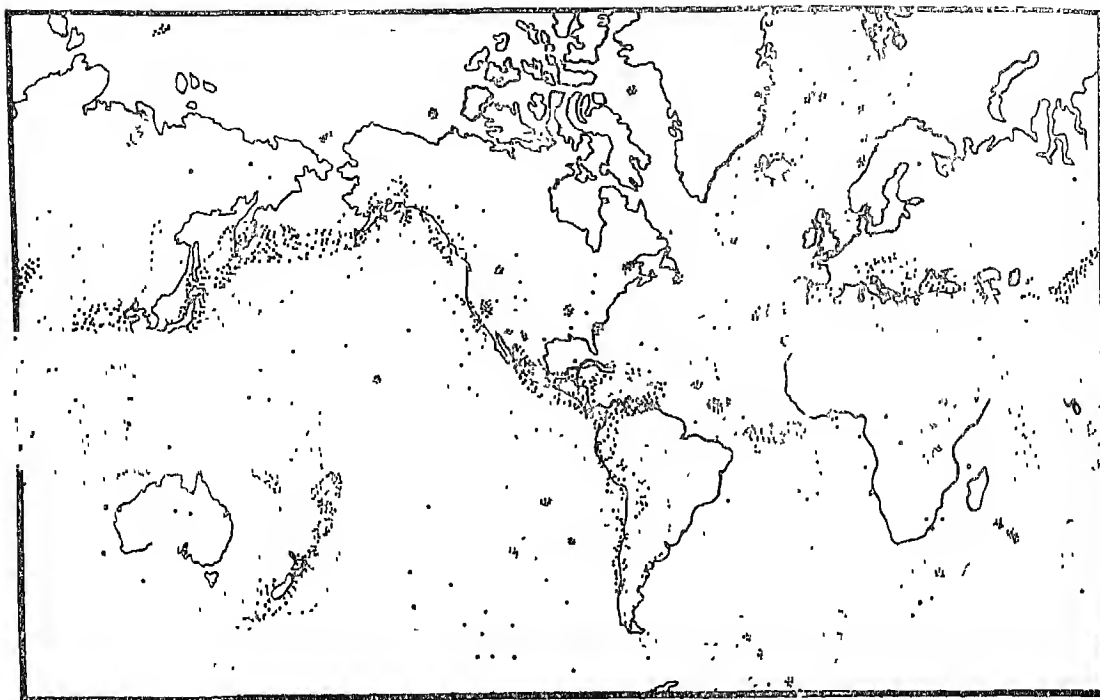
FIG 2 18   *The belts of seismic activity*

chistan mountain belts and also in the **Pamir** regions beyond Kashmir. A large number of earthquakes have been recorded in North India and in Himalayan mountain belts during historic times (See Figure 2 18)

Volcanoes, Geysers, Hot Springs and Fumaroles

All these are forms of what geologists call *igneous activity*. Igneous is derived from the Latin word 'ignis' meaning fire All igneous activity is caused by underground heat Exactly where and how this heat is produced is not clearly known but some of it perhaps come from radioactive minerals. Other possible sources of heat are chemical reactions in the earth's crust, it is perhaps also produced occasionally by friction as big sections of crust shift and rub against one another Perhaps some heat also comes from the very hot mantle of the earth which may be in a plastic state All this heat, and pressure from the weight of the bedrocks,

are constantly at work on the materials that makes up the crust Deeper down, heat and pressure probably keep the material in a plastic or doughy form which geologists call magma Hot springs of water are produced by water which has passed over hot rocks underground. This water is mostly rain water that has worked its way down through cracks. Because of the heat and pressure this water is able to dissolve more minerals than it could normally Hot springs generally occur in regions of active or recent volcanism. Japan and New Zealand are famous for their hot springs. In Bihar and West Bengal there are several hot spring areas.

Concept of a Volcano A volcano is generally thought of as a steep conical mountain having a crater at its top, from which at intervals, gases, rock fragments, bombs and lava flows are ejected This concept fits Vesuvius, the world's best known volcano, near Naples in Italy, and

because of it, this picture has popularly come to be regarded as typical of all volcanoes A world survey shows, however, that many of the volcanoes diverge greatly from this picture Technically speaking, a volcano is an opening in the earth through which heated matter rises to the surface and around which it builds a more or less cone-shaped hill The opening or vent through which the hot material rises is the crater In addition to the centrally situated main crater, volcanoes may have one or more subsidiary craters on the flanks of the cone
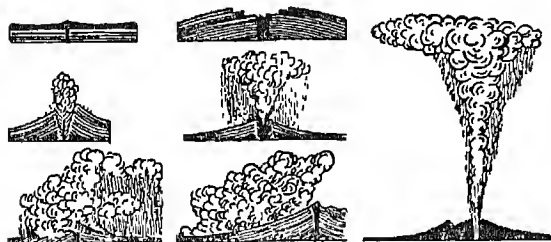

FIG 2 19 *The formation of a volcano*

Thus, the essential feature of a volcano is an eruptive apparatus, chiefly a conduit that connects the interior with the exterior of the earth This conduit is often referred to as the throat of a volcano The more or less conical structure that is built around the orifice of the conduit is called the volcano edifice The term 'volcano' is customarily used, however, to include both the vent and hill or mountain built around the vent.

Types of Volcanoes Studies show that volcanoes display a great variety in their characteristics In volcanoes of an explosive type, the eruption is very violent and of a short duration and the ejected matter consists of mainly solids and gases At the other extreme are the quiet type of volcanoes which erupt with very little violence Molten lava flows down when boiling and sputtering occurs in the crater Most of the volcanoes are intermediate between these two extremes, where alternating solid and liquid materials are ejected with considerable force. Thus three types of volcanoes are recognized— explosive, intermediate and the quiet type.

To the human mind volcanic eruptions are the most impressive of all geological activities because of the immensity of the forces displayed, magnitude of the results so rapidly achieved and the disastrous consequences that so frequently ensue

Although an exact tally has never been made, it is quite certain that the number of volcanoes on the earth runs to several thousand, of which only four or five hundred are now active It is customary to classify the volcanoes that have erupted within the experience of man as active, the others are considered extinct This distinction between active and extinct volcanoes is not rigid, for a volcano may lie dormant for many centuries and then resume activity Intervals of comparative quiet or of complete calm may alternate with periods of violent outbreaks A period of ejection of material is called an eruption. Volcanoes range in size from small cones hardly larger than a beehive to some of the loftiest mountains on the globe Many of the grander peaks of the Andes are volcanoes, some of these are active, such as Cotopaxi in Ecquador, which has the distinction of being the world's highest volcano, 6000 m (19,600 ft) in altitude It has a crater half a mile wide and 1500 ft deep Volcanoes of Hawaian islands rise from the floor of the Pacific Ocean at depths of 3500 to 4500 m (i e , 14,000 to 18,000 ft) Since their highest summits projects 3500 m (14,000 ft) above sea level, they attain a total height of over 9000 m (30,000 ft)

In a volcanic eruption the crust is broken through up to the mantle and the heat and pressure of the mantle are locally and partially released through the vents One of the biggest eruptions recorded by man is that on Krakatoa, a volcanic island in Sunda Strait. On Sunday, August 26, 1883 it started as a series of explosions. In a few hours, the explosions developed into a gigantic spasm that blew two craters to bits and left water 900 ft deep in one place where the island had been 2600 ft high The noise was heard in Australia and the pressure waves set up by the transmission of sound were

recorded all over the world. Ocean waves resulting from the event drowned 36,500 persons in the coastal regions of western Java and southern Sumatra The dust and ash went up 30 km into the atmosphere and lingered there for several years. The ash was thrown into air and carried by air currents to all parts of earth and fell in measurable quantities on streets in European cities After a whole year, the sunsets were still coloured and rendered dim by the dusty air even in distant countries and measurements showed that the sun's heat reaching the earth's surface was only 87 per cent of the normal value.

On February 28, 1943, a Mexican farmer named Pullido had a unique and terrifying experience He witnessed the birth of a volcano. The volcanic eruption was in full blast. Three days later the cone was 300 ft high and erupting at the rate of 17 explosions a minute On its first birthday, a year later, the Paricutin volcano had reached a height of 1410 ft During the first year Paricutin erupted lava and cinders at the rate of 1,400,000 tons a day With its continuous activity Paricutin falls into a class of volcanoes known as Strombolian from the famous cone in the Lolpar islands which, as the crater lights up the clouds at night, is called the 'Lighthouse of the Mediterranean' Stromboli seems to have been in continuous eruption since the time of the ancient Greeks who mention it. Another type of volcano is Vesuvius, which is characterized by spells of violent activity with tremendous explosions with comparatively little lava, alternating with periods of almost complete quiescence

Indian Volcanoes Though tertiary volcanism has been widespread in the Himalayas, Burma and Baluchistan, recent volcanic activity is known only in the Barren Island and Narcondan in the Burmese Arc and in the Nashkit in Baluchistan. There are no living or active volcanoes anywhere in the Indian region The Malay branch of the line of living volcanoes—a part of the Sunda Chain—if prolonged to the north would connect a few

dormant or extinct volcanoes belonging to this region Of these the most important is the now dormant volcano of Barren Island in the Bay of Bengal to the east of Andaman Islands It occupies an area of little over 3 sq miles and the ridge is 600 to 1000 ft high, the central cone rising to 1015 ft above the sea level It was seen in actual eruption in 1789, 1795 and 1803 Since then it has been dormant Another volcano along the same line is that of the island Narcondan, a craterless volcano From the amount of denudation that the cone has undergone it appears to be an old extinct volcano A third example is the volcano of Popa, situated about 50 miles north of the oilfield of Yemangyaurgi One more volcano within the Indian region but far on its western border is a large extinct volcano, Koh-i-Sultan, in Nashkit in Western Baluchistan Further along the same alignment is the Koh-i-Taftan in Iran which is said to be still active Among the volcanic phenomena of recent age is the crateriform Lake of Lonar Its exact origin is uncertain, although it is ultimately perhaps connected with volcanic action An effervescent volcanic eruption in 1756 of the Pondichery coast threw up large volumes of ashes and pumice and built up an island two miles long while the eruption lasted.

All the phenomena associated with the movement of hot molten and vapourous matter are included in the broad term 'volcanism' Volcanism is one of the important constructional or earth-building activities Most of the material ejected by a volcano is either liquid lava or fragments of partially or completely solidified rock in addition to astounding quantities of steam and ash Steam is discharged by active volcanoes in immense quantity, as indicated by the great height and enormous volume of the clouds that accompany many eruptions The composition of gases during an actual volcanic eruption is not directly known, because of the difficulties of studying a volcano under such conditions and of capturing gases uncontaminated by atmospheric gases. However, it is inferred with good reason from indirect evidence

to consist chiefly of steam. It is estimated that, on an average, in 100 days of activity volcanoes discharge nearly 460 million gallons of water Besides steam, other gases and volatile products are exhaled by volcanoes Amongst these are gases like carbon dioxide, hydrochloric acid, hydrofluoric acid, hydrogen and various compounds of fragmental material and ash (volcanic ash) These materials expelled into the air during a volcanic event are collectively called 'pyroclastic material' The ejected products after cooling, in part are composed of compact solid rock and in part are of a spongy, cellular, or vesicular character The character and appearance of the molten material pouring out of the surface, known as 'lava', depend on several things like composition, viscosity and the temperature of the magma or the material of the mantle It is roughly estimated that the erupted magma will be at a temperature of nearly 1200°C Volcanoes in general give direct evidence of the state and composition of the mantle in the region connected by vents through the crust to the volcanic openings

Volcanic phenomena require us to infer the presence of masses of magma underground that supplied the lava and pyroclastic products Any explanation of the causes of igneous activity must be based in part on inference, for the depths of the earth cannot be observed directly At depths of several kilometres it is probable that the temperature is high enough to melt all rocks at surface pressure. But the enormous pressure at that depth prevents the rocks from being converted to the liquid state. Perhaps a delicate balance between the effects of temperature and those of pressure is normally maintained At certain places, however, the pressure may be released or decreased, as a result of which the temperature becomes the dominating factor and local pockets of fluid magma are formed If the impelling force is sufficiently strong, then some of this molten magma may burst forth as volcanoes and fissure eruptions

The span of life of active volcanoes differs greatly Mt Etna, we know from written testi-mony, has been erupting for the last 2500 years much as it does now Its great volume, compared to its slow rate of growth, makes it probable that at least 300,000 years have been required to build this grand volcano On the other hand we know from geological evidence that Etna did not begin to erupt until the middle of the Pleistocene, the most recent of geologic time epochs From this standpoint, Etna is a comparatively youthful volcano During all its life a volcano is subject to weathering and erosion Its height and appearance at any given time are determined by the balance between this destructive and its own constructive or building power.

Volcanoes are commonly associated with mountain-making and earthquakes in regions where the earth's crust is weak Perhaps 90 per cent of the active and recently extinct volcanoes are located in two long, narrow, mountainous belts adjacent to deep ocean basins Outside these belts the only volcanic area of any great importance is Iceland, with its twenty-five or more active volcanoes One of the great belts, or series of belts, of active and recently extinct volcanoes is the so-called Pacific Girdle of Fire that forms an intermittent ring of volcanoes which can be traced around the earth more or less parallel with the equator, and for the most part north of it

Geysers Geysers are eruptive hot springs from which a column of mingled steam and water is explosively ejected at intervals The name comes from the Icelandic district of Geysir, where this phenomena was first noted and described In Iceland there are thousands of hot springs in all stages of transition, from pools of hot water, through simmering or quietly boiling pools, to periodically erupting geysers.

The Mechanism of Geyser Action The mechanism of geyser action is not clearly understood Temperature measurements show that the boiling point is reached some distance below the surface of the pool, but the weight of the overlying column of water prevents the water from flashing into steam It is believed, however, that
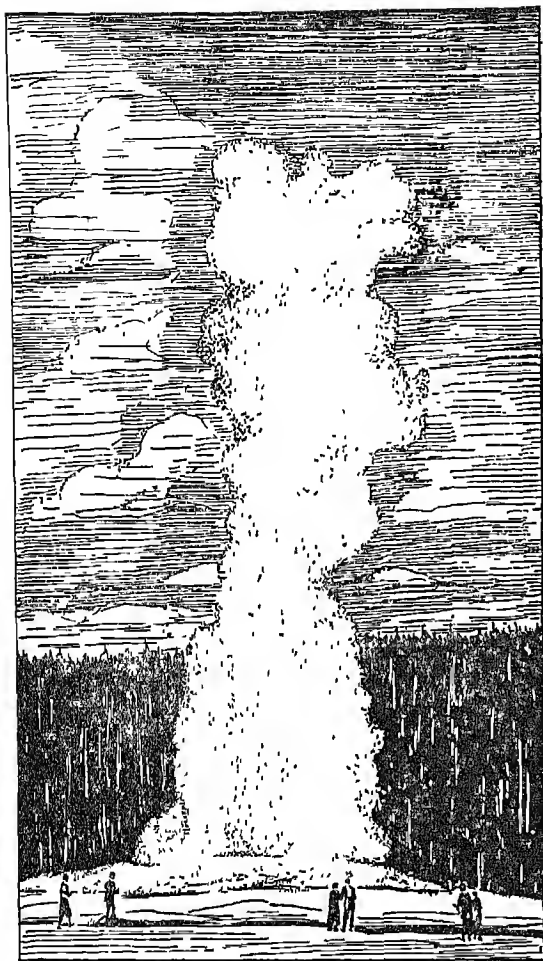
FIG 2 20   *A geyser*

heat is conducted into the water column, or rather the network of channels, from the surrounding hot rocks, or from super-heated steam The temperature is therefore constantly rising, until at last a small pocket of water passes into steam, and causes an overflow at the surface. This acts as a trigger, it relieves the pressure on the column sufficiently for all of it to expand explosively into steam, thus causing the eruption. Afterwards the system fills up again with hot water, and the whole process is repeated after a longer or shorter interval As geyser action depends on a delicate balance

between water supply, pressure, rise of temperature, and probably the shapes of the channels, it is not surprising that the phenomenon is, in general, irregular and short-lived Thus the Great Geyser, always rather irregular in its period, has completely ceased erupting since 1918 A well-known and beautiful geyser is the 'Old Faithful' It spouts 15,000 gallons of steam and boiling water 150 ft into the air every 65 minutes or so. Beneath every geyser is a looping channel running down into a region of very hot rock Underground water leaks into this channel and is heated by the rock. However, some of the water gets so hot that it changes to steam. The Great Geyser of Iceland gives out an erupted column of estimated height of 90 ft. The region of fumaroles, geysers, and hot springs is subject to sudden changes In Yellowstone National Park, for example, the system of underground channels was badly disrupted by the earthquake of August, 1959. Hot springs became geysers, geysers turned into hot springs, and some of these went out of action entirely. Even the 'Old Faithful' changed its time-table.

Fumaroles

The word 'fumarole' is derived from the Latin word 'fumor' which means 'to smoke' These are fissures of vents through which gases are ejected. These fumarolic gases are very hot and sometimes reach temperatures as high as 650°C. The hot gases rise through surface fissures from the magma far below The hot underground gases are sometimes so hot that they can dissolve metals such as iron, copper and lead. The term 'fumarole' is used also for high-temperature steam emission At lower limits of temperatures fumaroles pass into boiling springs and geysers. Fumarole regions include Yellow Stone National Park and Valley of Ten Thousand Smokes in Alaska The most spectacular recent example of steam jet activity what that which occurred in the valley of Ten Thousand Smokes in connection with the great explosion of Katmai Volcano (Alaska, in June,

1912) As activity wanes, fumaroles degenerate into hot springs and geysers. There are three main regions where hot springs and geysers occur on a large scale: the Yellow Stone Park in U S A, Iceland, and New Zealand Mineral substances are usually dissolved in the hot waters, of which calcium carbonate and silica are the chief components As the water overflows it cools, and the calcium carbonate (travertine) or silica (siliceous sinter) is deposited as queerly-shaped mounds around the springs, or, if the springs are situated on an interrupted slope, as in the Yellow Stone Park, the deposits build up step-like terraces, often dazzlingly white, but occasionally coloured, which form spectacular scenic features. The beautiful pink sinter terraces of Rotomahana in New Zealand were unfortunately destroyed in 1886 by an eruption from the Tarawera volcano.

Meteorology

Whether you live in a big city or in the open countryside, you must have sometimes looked at the sky and been deeply impressed by its beauty or struck with awe at its vast expanse No wonder man has always keenly observed the sky. He has also tried to understand the 'whys' and 'hows' of the happenings there. He has speculated why at times the sky is completely covered with dark, thick clouds; why sometimes incessant rain pours from the cloud, or blinding strokes of lightning rend the darkness, why violent wind mow down the trees and dwellings in their path, or, why the sky is sometimes serene, without a speck of cloud

There is evidence that in India our fore-fathers were curious about the various occurrences in the skies and sometimes described them as the work of the *devas* Being an agricultural society, the people depended on the rains for a good harvest. It is believed that a measuring device for rain existed as early as the fourth century B C, and our ancestors had defined units, called *drona adhaka* and *palas*, for measuring rainfall. In ancient works like the *Manu Smriti* and *Artha Shastra* (dated about third century B C.) there are *slokas* devoted to weather and the phenomena associated with it In the sixth century A D, Varaha Mihir compiled a compendium almost entirely devoted to meteorology and related subjects, containing numerous *slokas* devoted to the phenomena of weather and to observations, predictions and

other speculations regarding it All of these cannot be called scientific in the light of present-day knowledge. However, many of these show keen observational power and deep intuitive knowledge

In the European tradition, too, the study of weather has very ancient origins, dating back to the time before Aristotle, who gave the name 'meteorology' to weather study The invention of the thermometer and barometer in Europe in the seventeenth century is considered to be the beginning of modern meteorology The atmosphere is a gaseous envelope which surrounds the earth and is bound to it by the earth's gravitational attraction The weather phenomena we have been talking about occur in the earth's atmosphere The earth and a few other planets have atmospheres The earth's atmosphere consists mainly of nitrogen and oxygen, a small amount of water vapour, and minute traces of carbon dioxide and several other constituents. This envelope is believed to extend to very great distances Above the height of some 700 km, the gaseous molecules of the atmosphere begin to escape into space This region may be considered to be the top of the atmosphere and is called the 'exosphere'. About half the total mass of the air in the atmosphere is confined to below 6 km (18,000 ft) and three-fourths of the mass to below 12 km (35,00 ft) above the surface of the earth. On certain other bases, about which you will learn more in the later sections, the atmosphere can be divided into
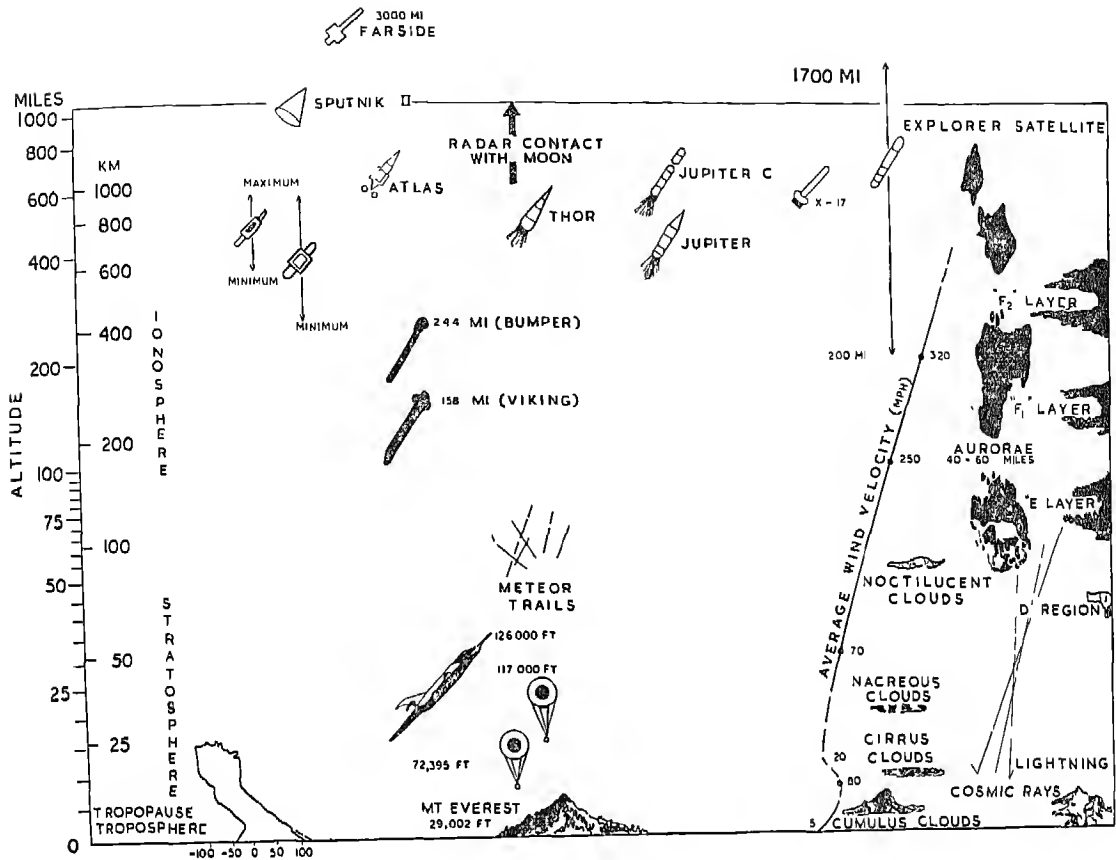
FIG 3 1.

layers The lowest of these is the troposphere (10 km), then comes the stratosphere (from 10 to about 80 km), and finally, the ionosphere (above 80 km) Ordinary weather phenomena, involving rain and clouds, occur in the troposphere since practically the entire water content of the atmosphere is confined within the tropospheric layer.

The study of the numerous physical and chemical processes going on in the atmosphere, and its motion and interaction with the underlying surface, constitutes the subject-matter of meteorology This study will enable us to understand the manner in which the atmosphere behaves, and thus we may be able to predict its future states Literally, the Greek word *meteoros* means lofty or elevated, and *logos*

means discourse Meteorology comprises the study of both weather and climate

Climatology

Try to remember a day in the month of July, no matter in which part of India you may be living, and recall the condition of the atmosphere on that day It might have been a day with the sky overcast with cloud, and the sun out of sight, or a windy day with low clouds and incessant rain, or it may have been a cloudless day with bright sunshine, making you feel hot and sticky, or again, it may have been a pleasant day with a few light showers, or with some light clouds slowly drifting across the sky Each of these days represents a different type of weather. When we consider a very large number

of days in July and try to get an average picture of the weather, we are thinking of the climate of that place in the month of July The average picture of a day that we get may resemble one of the above types more than the others, but may not be identical with any one of them If we try to express this idea in numbers, we will have to take measurable quantities such as maximum or minimum temperatures, the daily rainfall, or the relative humidity of the air, expressed as percentages The combination of these values would be characteristic of the weather of a particular day, and would vary from day to day We can collect these values for as many days as possible in a month and find the averages. These average values give us some idea about the climate of the place However, we have to have some other figures in addition to the above averages, such as the highest or lowest figure ever recorded during the period for which the data is being examined These highest and lowest figures give us an idea about the range of variation in the temperature, humidity or rainfall For an exhaustive study, these variations must be examined more thoroughly Besides, the study of climatology offers some explanation of the causes of such variations

The climate of a place depends in a complicated manner on several factors. One of the important factors is the latitude of the place, which as you know, determines the inclination of the sun through the year, the Greek world *klima,* from which the word 'climate' has been derived, means inclination Obviously, the ancient Greeks realized the importance of the sun's energy in determining the climate of a place.

At a few places in India, observations are available for over a hundred years Some of these places are Varanasi, Trivandrum, Roorkee, Poona, Madras For these places, the values of the maximum and minimum temperatures and rainfall, and other figures are available for a period of over one hundred years If you consider only the month of July, the temperature and rainfall values for more than one hundred Julys have been collected and recorded in charts

and tables If we take the averages for the total period, and then separately for the first half and the second half of the century, will the three corresponding average values be the same?

This question, in fact, is the same as the question often asked: 'Has the climate at these places changed during the last century?' The matter has been very carefully examined with the help of observations taken at a number of places in the world, which have continuous records of over a hundred years The stations were chosen with care, so as to eliminate all those in which changes might be suspected to be due to defective records or man-made causes. The finding is that even if there are any changes, these are quite small However, if you consider periods of time not in hundreds of years but in thousands and millions of years, as the geologists do, the climate over the earth has certainly undergone large changes You have been told that the earth was very hot in the beginning and has gradually cooled down Geologists tell us that in the last few million years alone there have been many ice ages Between these ages of intense cold there were mild periods, and the rainfall and snowfall have varied greatly during the different epochs. When we consider periods of time on a geological time scale (of millions of years), we find that there have been large changes in the climate of the earth

The changes in the climate during the past one or two centuries, however, are negligible compared to the above changes.

The main factors which define the climate of a place are· (*a*) atmospheric pressure, (*b*) temperature, (*c*) wind flow, (*d*) humidity, (*e*) rainfall, (*f*) sunshine Each one of these meteorological elements has to be very carefully measured under standard conditions, preferably several times every day, throughout the year, for a large number of years The records must be carefully preserved. Nowadays microfilms are used for this purpose, and mechanical methods are replacing manual calculations Since the last twenty years or so, these measurements are

recorded at a fairly large number of places all over the world, both at the ground level and the upper levels of the atmosphere These measurements of pressure, temperature, humidity are recorded at various fixed levels above the surface of the earth up to great heights These records are preserved like the records of measurements at the ground level and provide data for a climatological study of the upper atmosphere.

When records have been collected over long periods, these are used for working out the averages According to the instructions of the World Meteorological Organization (W M O) the averages of the records for the period 1931 to 1960 are to be called 'standard normals' for international use These may be revised every decade and some countries have already worked out the normals for the period 1931 to 1960 The use of such normals throughout the world would bring about a great deal of uniformity These normals of climatological information are


FIG 3 2 Climogram
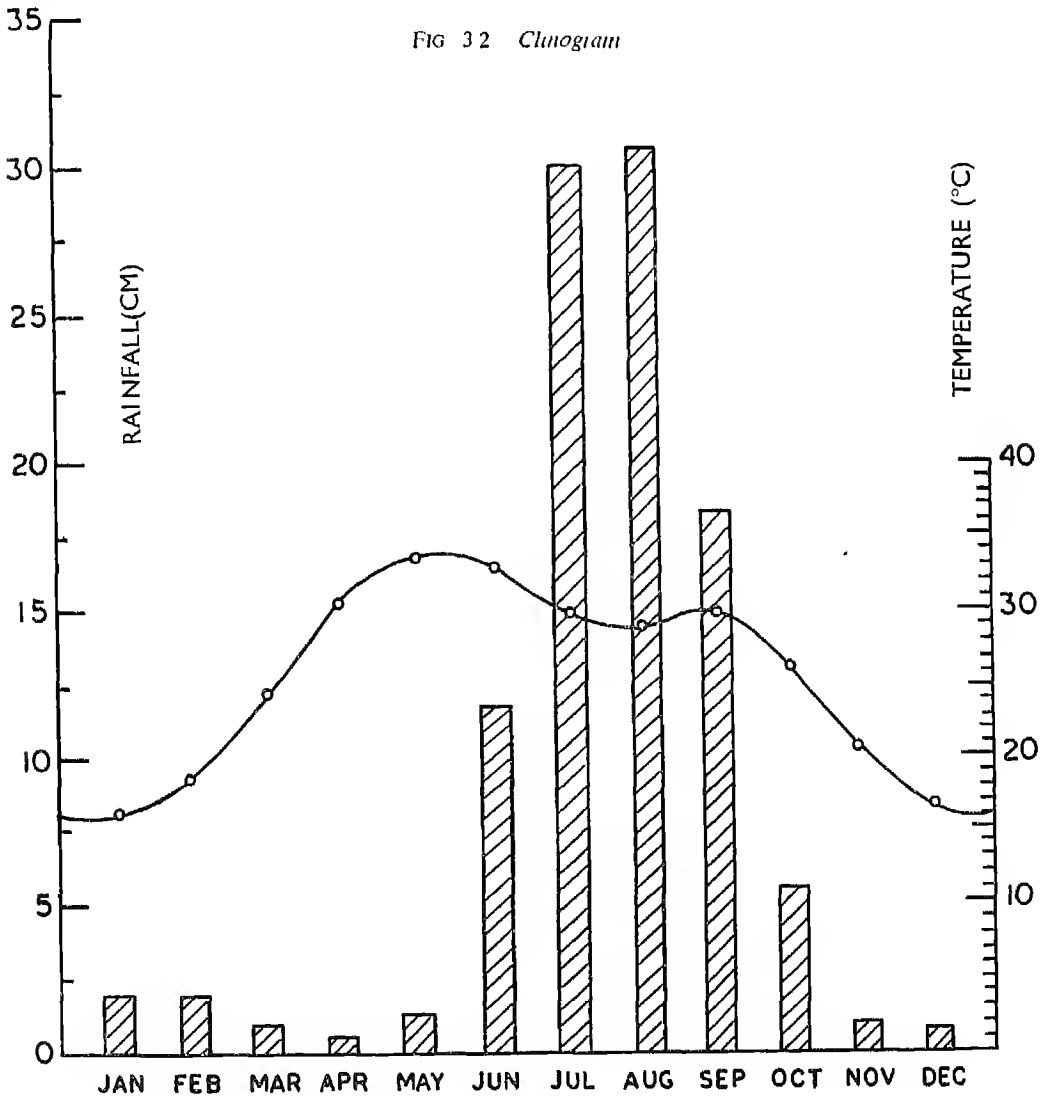
required by many people for purposes that range from the selection of a factory or dam site to the planning of a mountaineering expedition.

There are different methods of representing the climatological elements A common method is to prepare charts and maps on which places having the same value of an element are joined by smooth lines called isotachs In climatological atlases one finds a collection of such maps showing isotachs of mean annual and monthly values of different elements such as pressure, wind and temperature They also contain maps showing annual or seasonal rainfall

To represent the climate of a single station, climograms are prepared A simple variety of climogram gives the average monthly rainfall on which the average monthly mean temperature is also plotted Two examples are shown (Figures 3 2 and 3.3)

The variation of the climate of a place from

FIG 3 3   *Climogram*
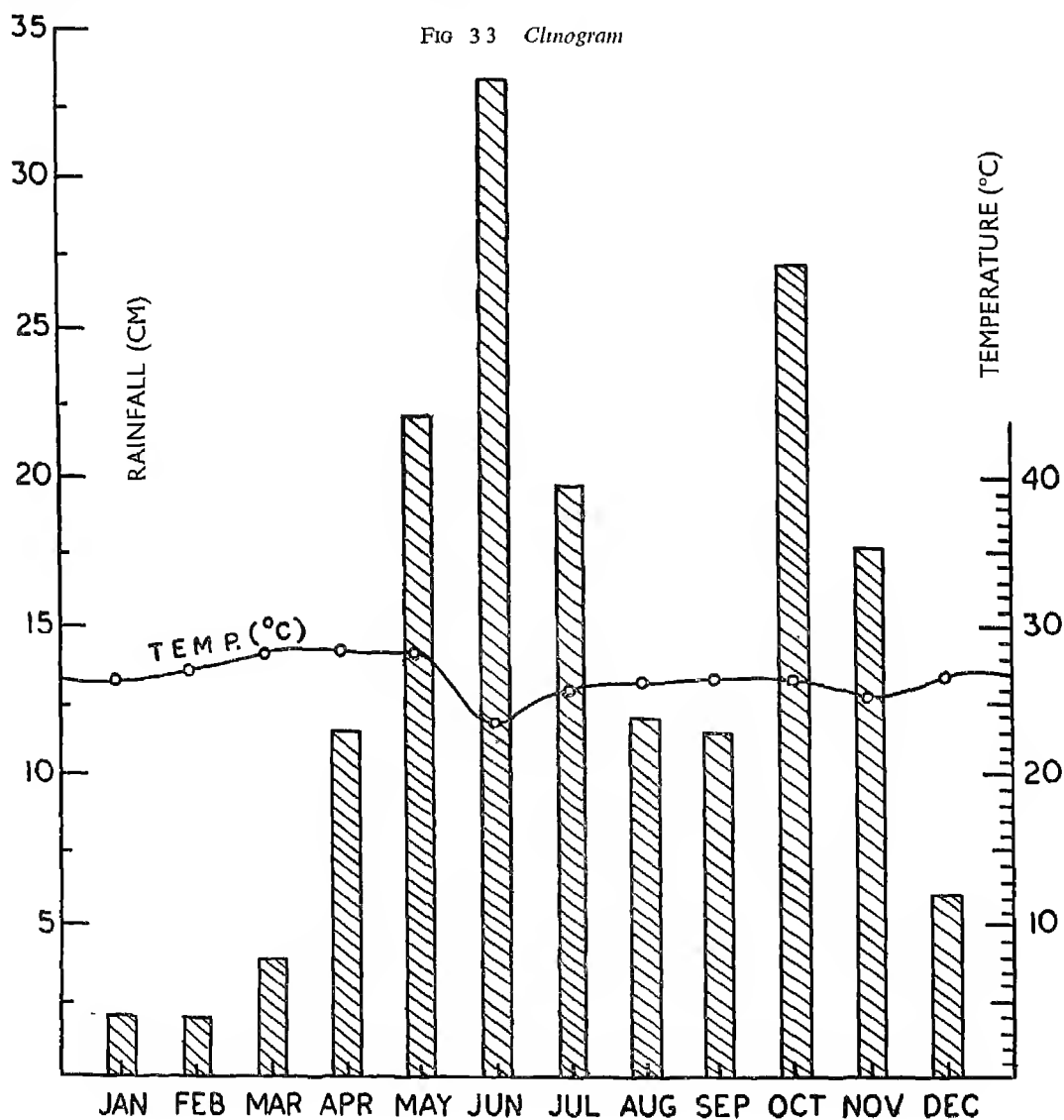
month to month during the course of a year is another aspect requiring some attention At some places the changes from month to month are gradual and very small, whereas at others, periods with markedly different climates can be clearly distinguished In the latter case, we call the markedly different periods the 'seasons' of the year.

The most important feature in the climate of India is the alternation of the seasons known as monsoons. These are caused by the two main wind systems:

(a) The system consisting of maritime (sea) air flowing to the land

(b) The system consisting of land air flowing to the sea

FIG 3 4

MEAN TEMPERATURE OF THE DAY °C
JANUARY
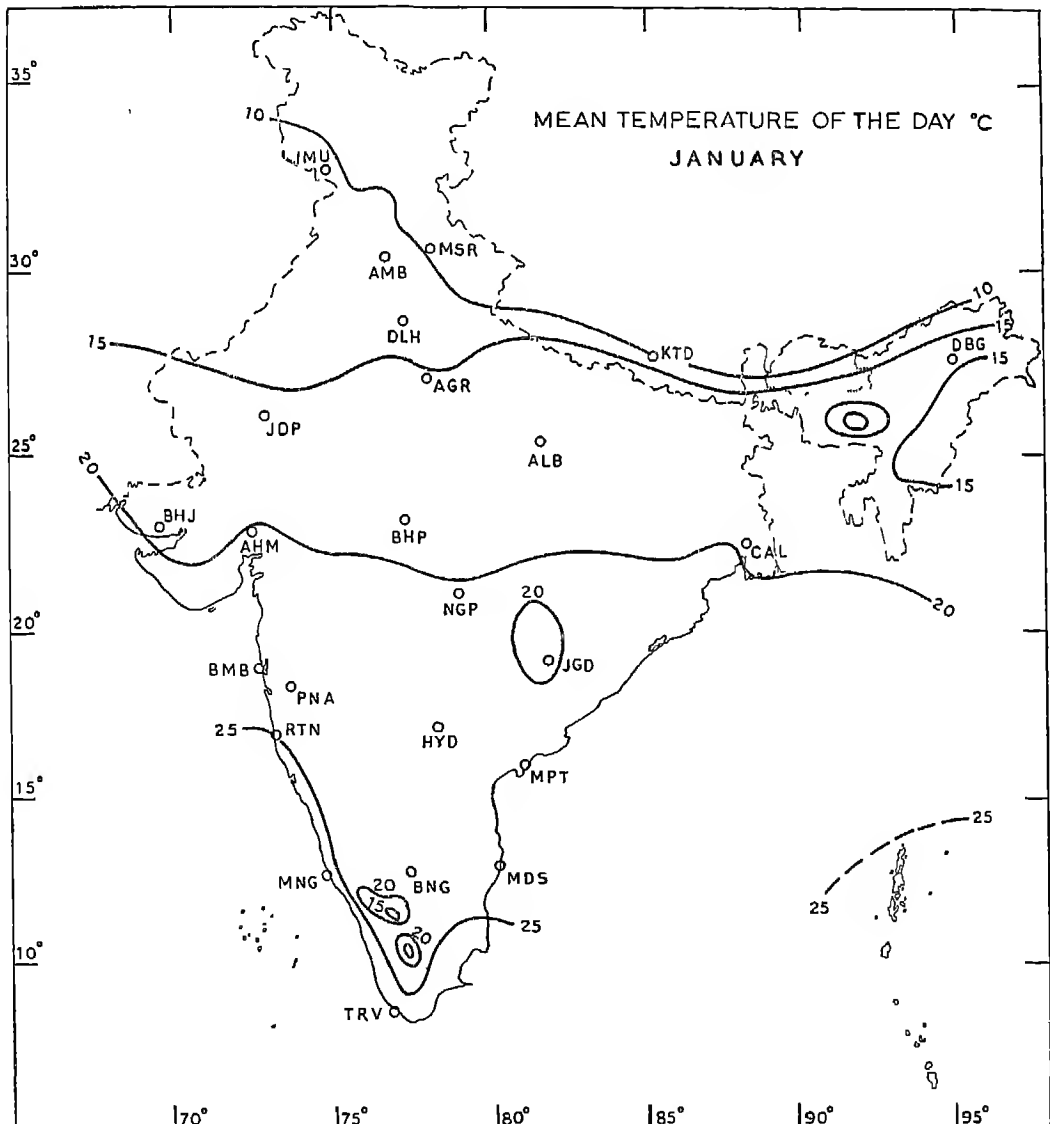
The first constitutes the South-west Monsoon, commonly called the monsoon which, incidentally, is the best known example of a large-scale monsoon phenomenon Between these two are interposed the transition seasons of the hot weather and the retreating monsoon season Thus the year is divided into four seasons: (*i*) winter (January and February), (*ii*) hot weather (March to May), (*iii*) S W. Monsoon (June to September), and (*iv*) post-monsoon (October to December)

In most parts of India the year is divided into well-marked dry and persistently wet periods, as the climate is greatly influenced by the two systems of winds mentioned above under (*a*) and (*b*) Only in certain parts of

FIG 3 5.
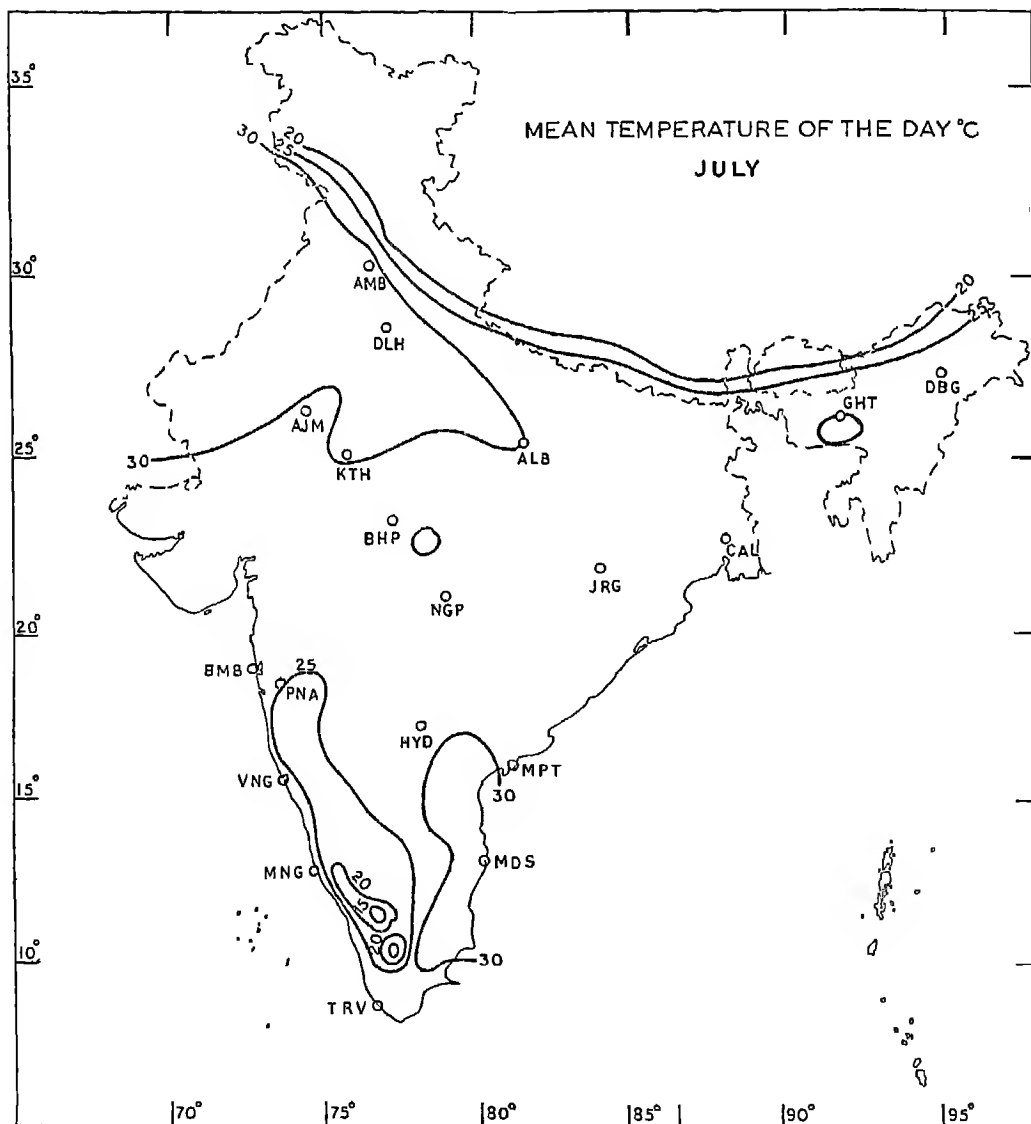
northern India there is a small amount of rainfall or snowfall during the winter In the east coast at Madras and south of the Peninsula, the second wet period is in the later part of October and November

Figures 3.4 to 3 7 on pages 81-94 give you some idea about the temperature distribution in the months of January and July and the seasonal and annual rainfall over India You will see from the two rainfall maps how closely the heavy rainfall follows the mountain ranges along the Western Ghats and amongst the ranges in north-east India This shows the very important role which mountain ranges play in bringing rainfall However, you have to remember that this is only one of the factors which

FIG 3 6

SEASONAL RAINFALL
JUNE TO SEPTEMBER
—— NORMAL DATES OF ONSET OF S.W MONSOON
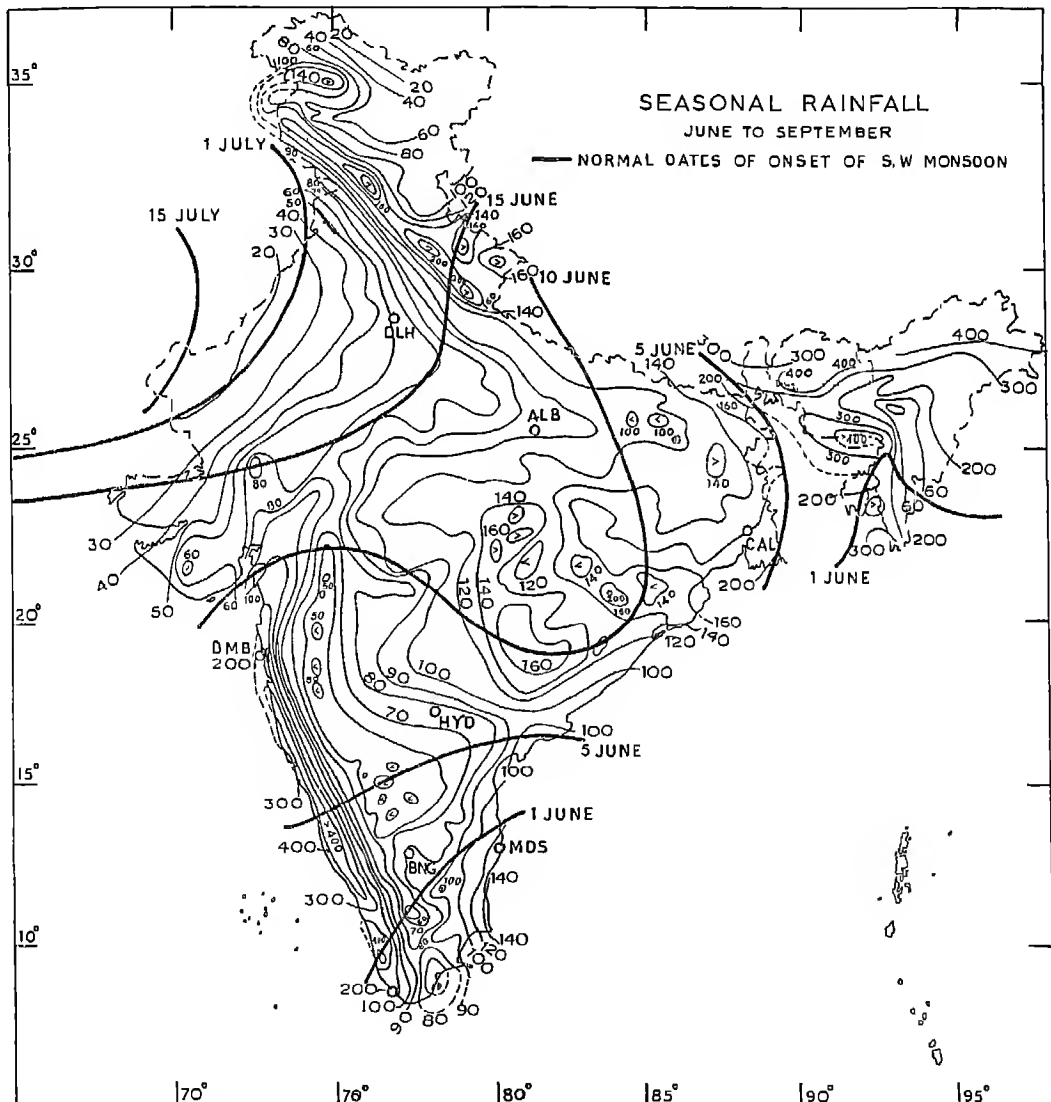
cause rainfall during the monsoon season in the Indian area

Another feature of the climate which you can clearly notice from Figures 3 6 and 3 7 is that a very large percentage of the annual rainfall over most parts of India occurs during the period included between the dates of the onset and retreat of the monsoon, shown on the maps

We mentioned earlier that the Greeks realized that the climate of a place depends on the inclination of the sun, which, in turn, depends on the latitude of the place On the basis of this idea the world has been divided into three climatic zones, demarcated by the latitudes The three zones are one hot belt, two temperate belts and two cold caps This is a classification

Fig 3 7

AVERAGE ANNUAL RAINFALL
(IN CENTIMETRES)
NORMAL DATES OF WITHDRAWAL OF MONSOON
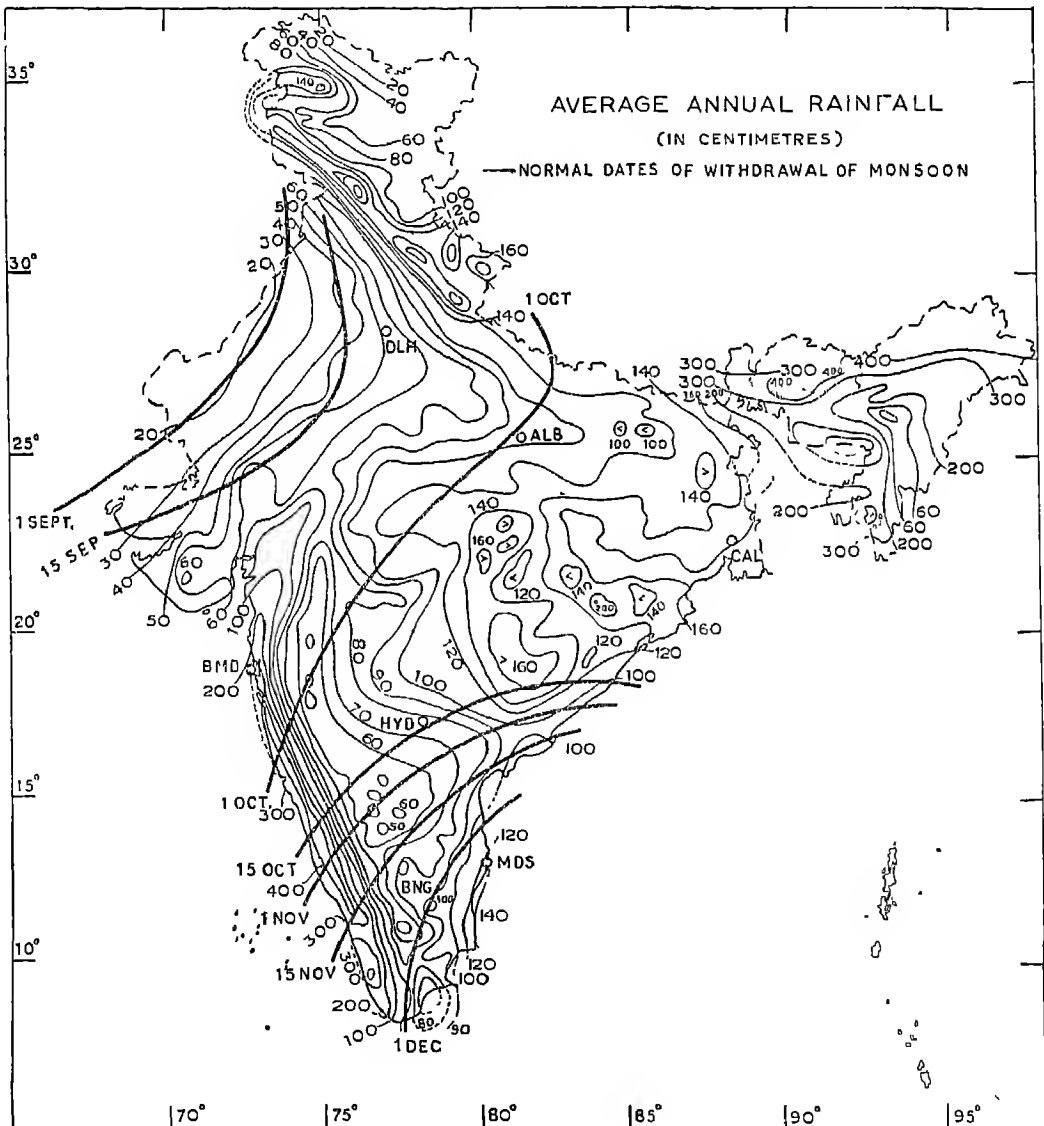
based entirely on temperature Actually, the zones are neither so simple nor are the boundaries so parallel to the latitudes The reason is that although the climate of a region is controlled by the sun's energy, it is influenced also by other factors, such as position relative to continents and oceans, altitude, local geography, etc The classification of climate for universal application is therefore fairly complicated and difficult

Physical meteorology

The object of the science of meteorology is to enable us to understand the occurrence of all the phenomena in the atmosphere on the principles of physics and chemistry, and ultimately to calculate their magnitudes with the help of mathematics This is a difficult goal to achieve because the science of weather is still an empirical field science The insurmountable difficulties characteristic of field sciences, such as availability of only partial data, also apply to meteorology.

The main source of energy received by the earth's surface and the atmosphere is the radiation from the sun, and all of it is received after it has traversed 93,000,000 miles of intervening space This solar radiation is in the form of electromagnetic waves and includes the heat and light we receive from the sun. The solar electromagnetic waves constitute a very wide range of wave lengths, extending from the very short gamma rays and very deep X-rays (10^{-10} m) to long radio waves (a few kilometres in length) Figure 3 8 gives a spectrum of these waves For meteorological purposes, the solar radiation is looked upon as consisting of only two kinds of waves (i) the short wave radiations, and (ii) the long wave radiations The earth's atmosphere allows the visible rays (short waves) to pass through freely, however, there is a sharp cut-off on the ultra-violet side. This is quite fortunate because these ultra-violet rays are injurious to human beings, animals and plants. On the long wave side, the atmosphere is not quite so transparent as it is in the case of visible rays The water vapour and carbon dioxide in the atmosphere particularly cut off certain wave lengths on the long or infra-red side of solar radiation At a greater height (22 km) the presence of ozone (O_3) plays an important role in the passage of short wave radiation through, and its absorption in, the atmosphere.

The atmosphere gets its energy mainly at the lower surface This surface may be either land or water Some amount of energy is radiated back from both these surfaces in the form of long wave radiation. One of the consequences is that the temperature of the atmosphere normally decreases as we rise above the surface of the earth This decrease continues up to a certain height above which it remains more or less constant, at greater heights, the temperature changes in a complicated manner This fact is confirmed by the temperatures as actually measured in the atmosphere As mentioned earlier, this forms the basis on which the atmosphere has been divided into layers

The energy from the sun falling over extensive water surfaces such as oceans or large inland lakes causes water to evaporate Some amount of evaporation also takes place from the land, particularly from portions covered with vegetation You are also familiar with the fact that when unsaturated air blows across a stretch of water surface, water evaporates into the air, lowering the temperature of the air at the same time A considerable amount of water thus enters the atmosphere in the form of water vapour You may be surprised to learn that the density of moist air is much less than that of dry air at the same temperature The density of water vapour and air at the same temperature and pressure are as $5:8$.

A major portion of the water vapour taken up into the atmosphere remains in the lower portion of the atmosphere, i e, mainly within the troposphere However, the distribution in the lateral dimensions varies very widely. For example, the moisture content may be al-
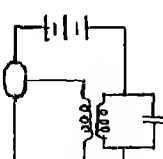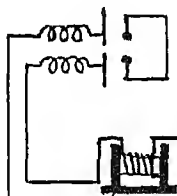
THE ELECTRO-MAGNETIC SPECTRUM
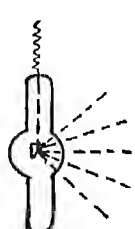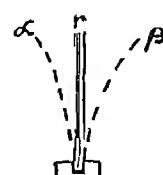
FREQUENCY CYCLES/Sec.	WAVE LENGTH (cm)				
3×10^{-3}	10^{13}		VERY LOW FREQUENCY WAVES		
			LOW FREQUENCY WAVES		
3×10^{-1}	10^{11}	A.C. GENERATOR	COMMERCIAL FREQUENCIES		THOMSON CIRCUIT
			AUDIO FREQUENCIES		
$10^2 \times 3$	10^8		LONG WAVES		
			MEDIUM WAVES		
3×10^5	10^5	RADIO SETS	INTERMEDIATE WAVES		
			SHORT WAVES		
			METRE WAVES		
3×10^8	10^2		CENTIMETRE WAVES		RADAR WAVES
3×10^9	10		MILLIMETRE WAVES		
3×10^{10}	10^0		SUB-MILLI METRE WAVES		
3×10^{11}	10^{-1}	HERTZIAN OSCILLATOR	DECA-MICRON		
			MICRON		
3×10^{14}	10^{-4}	VOLTAIC ARC	LIGHT NEAR ULTRA-VIOLET		
			FAR ULTRAVIOLET		
3×10^{17}	10^{-7}		BOUNDARY X-RAY		X-RAY TUBES
3×10^{18}	10^{-8}		SOFT X-RAY		
			HARD X-RAY		
3×10^{21}	10^{-11}	RADIO-ACTIVE ELEMENTS	GAMA RAYS		RADIO-ACTIVE

Column labels (vertical):
LOW FREQUENCY WAVES — RADIO WAVES — ULTRA WAVES — INFRA-RED WAVES — ULTRAVIOLET WAVES — X-RAYS — GAMA RAYS

ELECTRICAL OSCILLATION OF DIPOLES — MOLECULAR AND ATOMIC VIBRATIONS

CATHODE OSCILLATOR — QUARTZ MERCURY VAPOUR LAMP ARC DISCHARGE — RADIO-ACTIVE FISSION

FIG 38

most nil over arid, hot or extremely cold regions But the air may be completely saturated with moisture in tropical coastal areas. Further, wide variations occur over the same region from season to season. It is obvious that the presence of water vapour is the principal cause of the formation of clouds, rain or snow, and storms The latent heat of water is an agent for carrying significant amounts of heat energy into the atmosphere. When water vapour condenses to form clouds in the atmosphere, it imparts its latent heat to the immediate surrounding portions of the atmosphere and thus increases its energy It is believed that the energy of a cyclonic storm is chiefly derived from the latent heat of water. It represents
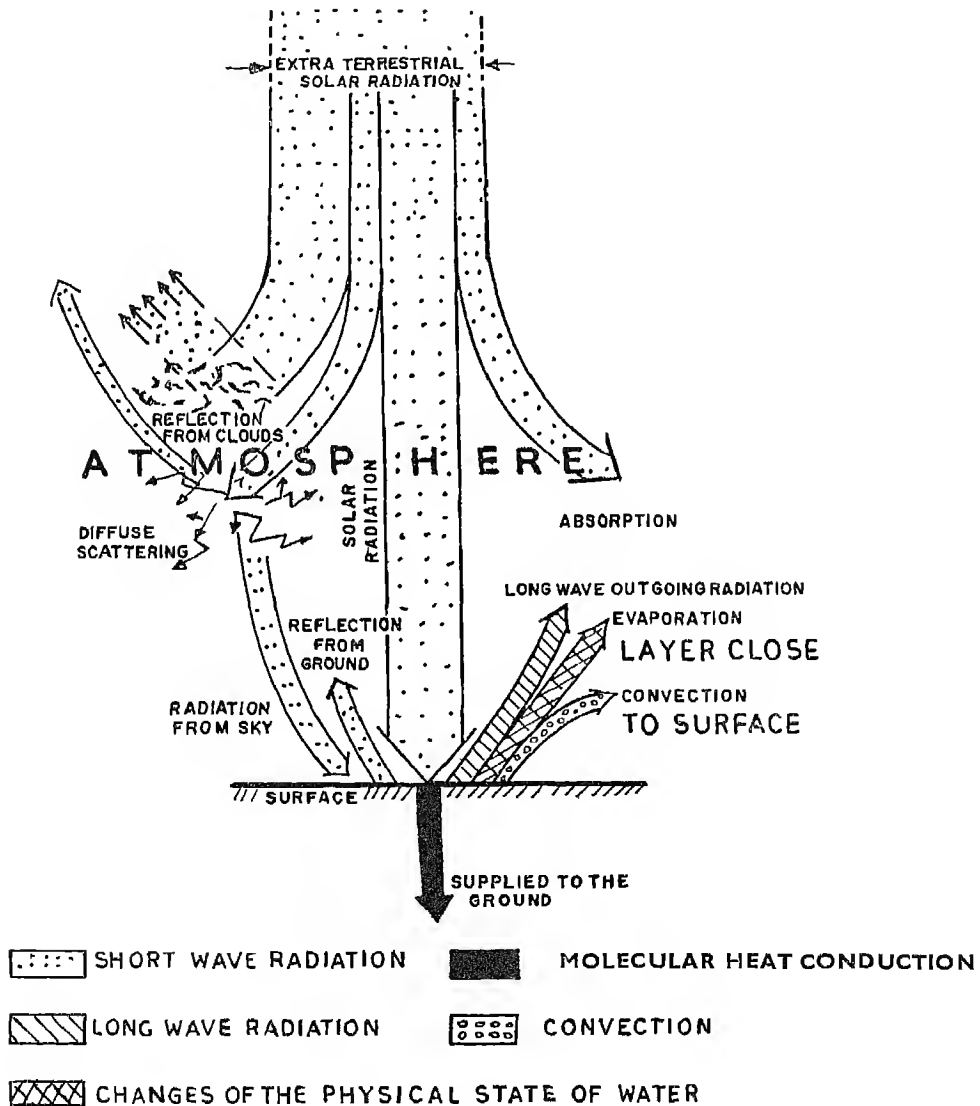

FIG 3 9   *The disposal of solar radiation*

qualitatively the disposal of solar radiation during its passage through the atmosphere The short wave and long wave radiations are transmitted differently through the atmosphere You will notice (Figure 3.9) that some amount of radiation is sent back to space by the surface of the earth, and by the atmosphere, including cloud tops Estimates show that nearly 43 per cent of the incoming short wave radiation is returned to space This is known as the *albedo* of the earth It is with the help of this radiation that the earth is seen or photographed from outside the earth by astronauts and space craft

As the temperature of the atmosphere does not change appreciably from year to year, the net gain and loss of energy by the atmosphere should balance However, elaborate calculations of loss and gain of heat in the atmosphere at different latitudes (principally based on Northern Hemispheric data) by several scientists show that these balance only at about 30° latitude On the equator side (0° to 30° latitude) the incoming energy is greater than the outgoing energy, and beyond the 30° N (30° to 90°) latitude the incoming energy is less than the outgoing energy This also applies to the southern hemisphere This excess of energy in the equatorial region is transported towards the poles by the movement of air from one part to another If the earth were not a rotating

sphere, the method of transfer of excess energy would have taken a simple form

In the equatorial regions the excess energy would have heated the air making it rise high in the atmosphere from where it would have moved towards the poles and descended to the surface at the poles after cooling Then the heavy cold air would have moved over the surface from the pole to the equator, where it would again rise, completing the great air circulation extending from the pole to the equator However, the rotation of the earth brings in a complication which prevents the formation of this huge hemispherical circulation Instead, this circulation breaks up into a number of component circulations (See Figure 10, in which both the plan view as well as vertical section on a much enlarged scale have been presented)

On a rotating globe, a given point on a latitude circle is moving at a different speed from that of another point on a different latitude circle Therefore a parcel of air moving from one latitude to another experiences a deflecting force In the Northern Hemisphere this deflection is always to the right and depends on the speed of the air parcel and on the latitude Thus, air moving northwards from the equator will be deflected to the right and will keep on changing its direction towards the

Fig 3 10a,b *General circulation of air*
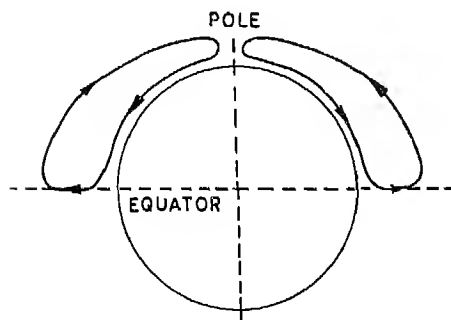
NON-ROTATING UNIFORM GLOBE

a
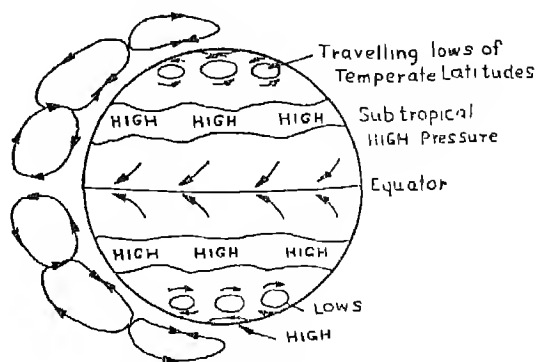
ROTATING UNIFORM GLOBE

b

north-east, and then towards east Similarly, air moving from a latitude of $23\frac{1}{2}°$ N (The Tropic of Cancer) towards the equator will be deflected to the right and thus will be moving from the north-easterly direction On a rotating globe, the air at the equator having risen to high levels begins to move towards the poles but gets deflected to the right on account of the deflecting force By the time the parcels of air reach $20°$ to $30°$ N latitude, they begin to move from west to east, thus constituting a westerly wind flow. As a result of this, there is an accumulation of air in this latitude band This is the subtropical high pressure band Air near the surface in this subtropical high pressure area moves towards the equator from the southern boundary of the high pressure area As mentioned earlier, on account of the earth's rotation the air moves from the north-easterly direction These are the very well-known Trade Winds which blow so constantly over the Atlantic and the Pacific Oceans and have been known to mariners for centuries From the northward side of the subtropical high

pressure area the air moves towards the pole in the north-easterly direction but on account of the formation of a number of travelling low pressures, a complex wind system results

The circulation of air in the belt between the equator and the subtropical high pressure area, therefore, is as follows air rises at the equator and flows north-eastwards as the subtropical high pressure moves towards the equator as a north-easterly wind This circulation has been known as the Hadley Cell since the eighteenth century Two scientists, working at the National Centre for Atmospheric Research in the U S A., and at the University of Stockholm (Sweden), have demonstrated the reality of the Hadley Cell by analyzing all the available data for one day They chose the 12th of December, 1957, from the International Geophysical Year period, and computed the globally-averaged north-south and vertical wind components against different heights and between $30°$N and $2\frac{1}{2}°$S latitudes The result is given in Figure 3 11 The thick black arrows clearly show how the Hadley Cell is formed by

FIG 3 11 *The Hadley Cell*
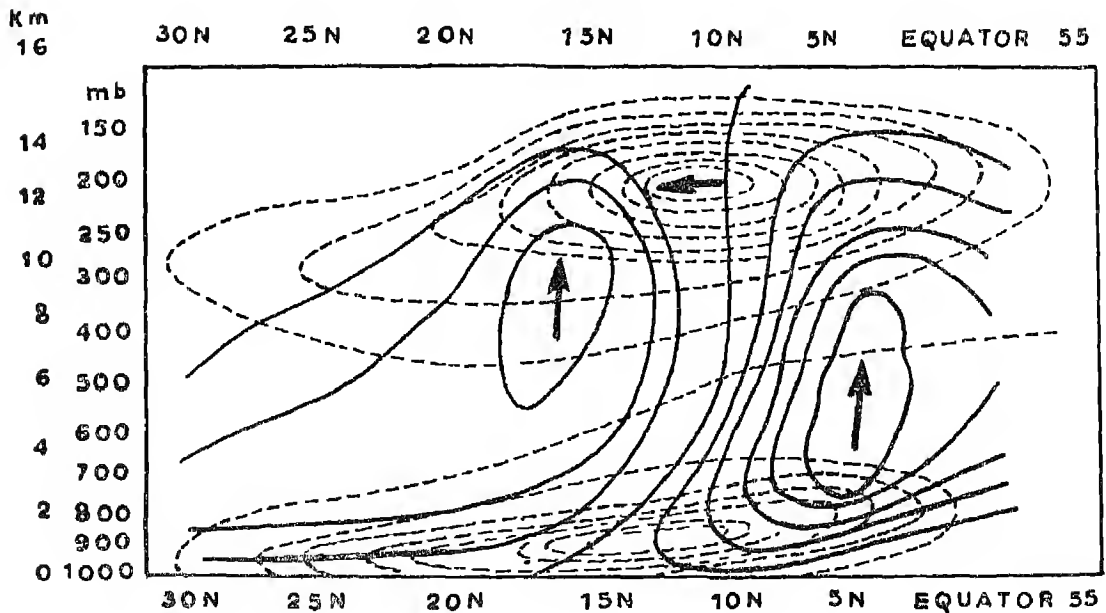
air rising at the equator, then flowing towards the poles at high level, descending in the subtropical high pressure areas, and finally moving towards the equator at the surface.

At upper levels, north of 20° to 30°N latitude up to the pole, the winds flow steadily from the west to the east and form the zonal winds of the temperate latitudes. The circulation is circumpolar and almost steady, it can be looked upon as the wind circulation in a counterclockwise direction round a low pressure at the pole.

The case of the Indian Ocean is slightly different. Because of the extensive land masses of the Asiatic continent, the high pressure is very pronounced during the winter but it is situated very much further north than 20/30°N latitude. The wind from the equator side of this high pressure blows from the north-east towards the equator. Over India it constitutes the land air blowing to the sea. But during summer the high pressure vanishes completely and, instead, an extensive low pressure area forms over the land. This causes air from the equator to move towards the poles and appear as the south-westerly wind system from the ocean to the land, these are the monsoons mentioned earlier.

With the upper level westerly winds (zonal wind of temperate latitude) is associated the 'jet stream'. This is the name given to the narrow meandering rivers of very strong winds (300-500 km/h or 200 to 300 mph) occurring at heights between 20,000 to 40,000 ft above sea level. The winds are strongest at the core of the stream. The jet stream usually girdles the earth, though its speed and width may vary during its run. When it lies at a northerly latitude it has slight undulations. However, as the jet stream shifts to lower latitudes, it develops large undulations. Aeroplanes flying at the height at which the jet stream occurs have sometimes encountered its winds. Flying against them, their speed has been reduced almost to zero, and flying with the stream the speed of the aeroplanes has increased spectacularly.

You must have watched vultures and kites circling in the sky and soaring to very great heights. These high-flying birds are known to utilize columns of rising air to climb to great heights without beating their wings or exerting themselves in any other way. Nowadays such rising columns are called 'thermals'. In thermals, the air parcels move upwards with considerable velocities. The horizontal displacement of air in the atmosphere is known as wind, while the vertical displacement is called 'currents'. On the whole, when averaged over

FIG 3 12   *The jet stream*

JET AXIS
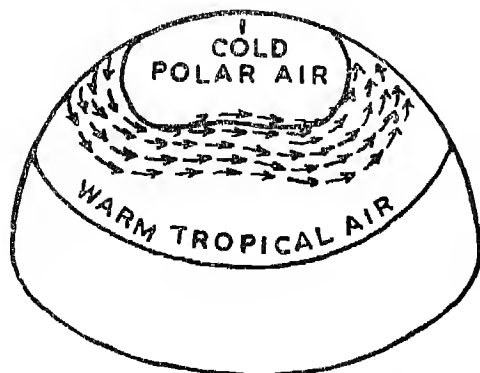
A. JET STREAM BEGINS TO UNDULATE
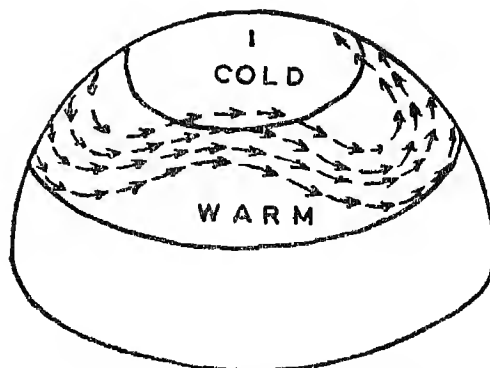
B. LARGE UNDULATIONS FORM AS JET STREAM SHIFTS TO LOWER LATITUDES

global dimensions, the currents are very small compared to the winds However, locally and for short periods of time, currents of considerable velocity can exist in the atmosphere.

The vertical motion of air is of very great importance As air rises it cools and condensation takes place and clouds are formed Under conditions of strong currents, clouds build up further into towering clouds reaching regions of the atmosphere where the temperature is below freezing point Slow but extensive currents over a very wide area are found in the so-called 'warm fronts'. From the time of World War I, European meteorologists, and later many others, have used the idea of 'warm and cold fronts' very usefully in understanding the weather in the temperate latitudes According to this concept, at a 'warm front', warm moist air rises over the cold air, and this gives rise to the weak currents just mentioned The warm air, when raised sufficiently, gives rise to extensive clouds and ultimately rain, this is typical of the 'warm front' type of weather situation. Even laymen in temperate latitudes know what type of weather to expect when they hear that a 'warm front' is passing over their city or town

As air passes over mountains, large currents are produced Aeroplanes inadvertently coming near mountains have been caught in the violent up- or down-currents. Glider pilots, particularly in the Alps, have considerable experience of these currents The airflows past and over the mountains produce up-currents as well as down-currents, sometimes eddies or whirls are produced. The up- and down-currents produce very characteristic clouds (standing lee-wave clouds) near the mountains, these are shown

FIG 3 13 *Clouds produced by up- or down-currents*

WAVE STREAMING

ROTOR STREAMING

ARROWS ON THE LEFT SHOW STRENGTH OF WIND ALONG STREAM LINES.
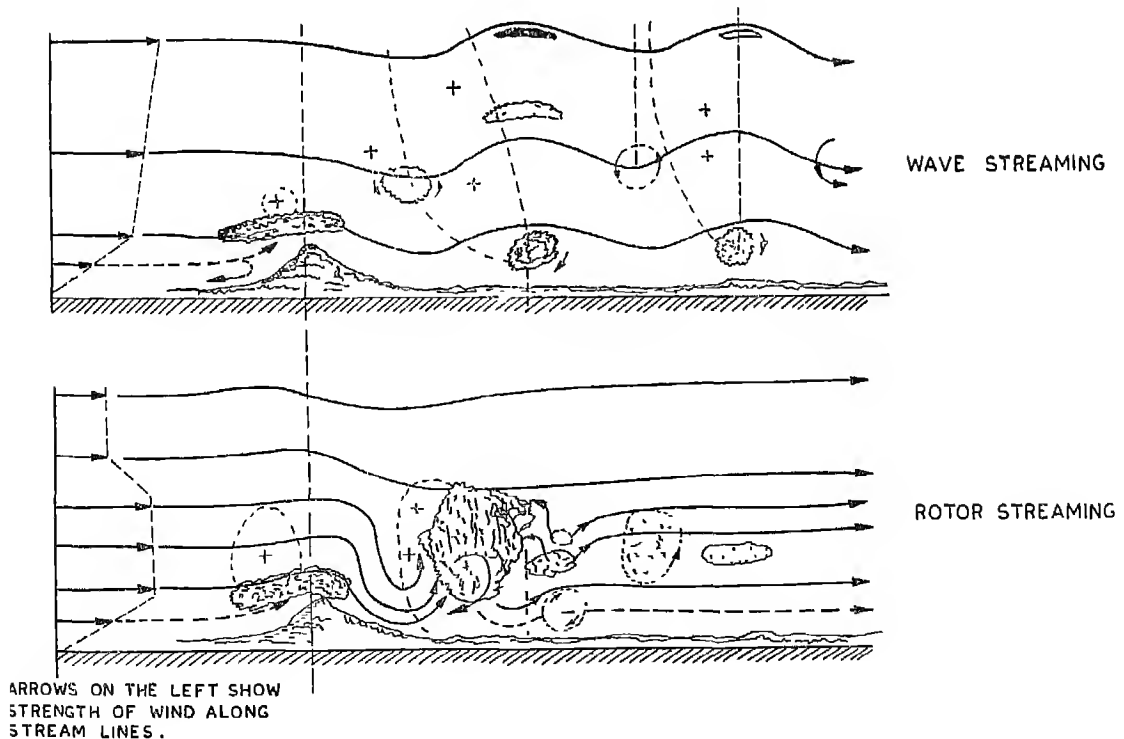
schematically in Figure 3 13 Under certain atmospheric conditions, and in large mountains, very violent and chaotic currents can be created which affect all levels of the free atmosphere as well as the surface of the mountainsides

If you pour some oil on water in a half-filled beaker, the layer of oil will remain on the surface of the water If you disturb the layers these will re-form when the disturbance is stopped. The layers are in *stable equilibrium* Under special conditions, with a great deal of care, you may be able to form a coloured and slightly heavier layer of another liquid on top of a layer of uncoloured water, in a beaker Of these two layers of liquid with slightly different densities, the heavier will lie over the lighter so long as the beaker is not disturbed even slightly. But the layers will overturn the instant you disturb the beaker, and separate layers will not re-form even after the disturbance is stopped. This is a case of *unstable equilibrium.* If you take a small probe and prick through the upper layer into the water layer below, you may be able to see a stream of coloured and slightly heavier liquid flowing through the hole to the lower layer and spreading in all directions

Now let us examine the question of stable and unstable equilibrium conditions further by considering the following examples Take an iron *karahi* from the kitchen, place it on a smooth surface, say a table or a smooth floor. Pour some heavy material, say sand, into the *karahi*. Now tilt the *karahi* to one side. When you let it go it swings back to its original horizontal position. The *karahi* is in stable equilibrium on the smooth floor Now take a well-sharpened pencil and carefully balance it on the tip of your finger, the pencil resting on its sharpened point. It will stay upright so long as you can keep it balanced on your finger-tip. But if you displace the pencil to one side it will not return to its original position but will topple over immediately This is a case of unstable equilibrium. In the atmosphere one constantly finds layers of dry or moist air

either in stable equilibrium or temporarily in unstable equilibrium Ordinarily the atmosphere is so laid in layers as to assume a stable equilibrium A critical test for this is that if a parcel of air is displaced upwards from its position of rest in a particular layer and if after its displacement to the new position it acquires a density greater than its surrounding, it will sink back to its original position, thus the layer is in stable equilibrium. If, however, the displaced parcel of air is lighter than its surrounding in the new position after displacement, it will rise further. The layer would now be in an unstable equilibrium

Before examining this important question of stable and unstable equilibrium of the atmosphere any further, we should understand what is meant by Dry Adiabatic Lapse Rate (DALR) and Saturation Adiabatic Lapse Rate (SALR) Lapse rate, in this context, means the rate of change (usually fall) of temperature with height If a parcel of dry air is changed from an initial pressure to a lower pressure adiabatically, so that the parcel of air is not allowed to exchange heat with the surrounding air, its temperature will fall. This fall for a given pressure change can be easily calculated with the help of the gas equation In the atmosphere, however, the decrease in pressure is equivalent to a change in height, for the pressure decreases as we go up Therefore, when the pressure exerted on a parcel of air is decreased, it can be considered to be equivalent to a rise through a certain height in the atmosphere We have already said that the temperature of the air in the parcel will decrease and this decrease can be calculated. Thus, for a rise of the parcel of air through a given height there will be a definite decrease in temperature. It is found that the value of the lapse rate works out to be 10°C for every kilometre rise of the parcel. This is the DALR and has a definite numerical value Now consider the case when there is some amount of moisture in the parcel of air we are adiabatically displacing. So long as the air does not become saturated there is

not much difference in the lapse rate from the DALR. But, as soon as the air parcel becomes saturated and is cooled further, condensation occurs and the latent heat is released, which raises the temperature of the parcel You will notice therefore that the saturated parcel cools to a lesser extent than the dry parcel. The Saturated Adiabatic Lapse Rate (SALR), unlike the DALR, does not have a definite numerical value, it may be as low as half the DALR.

Now let us apply the test of stable equili-

Fig. 3 14   *Stable and unstable equilibrium*
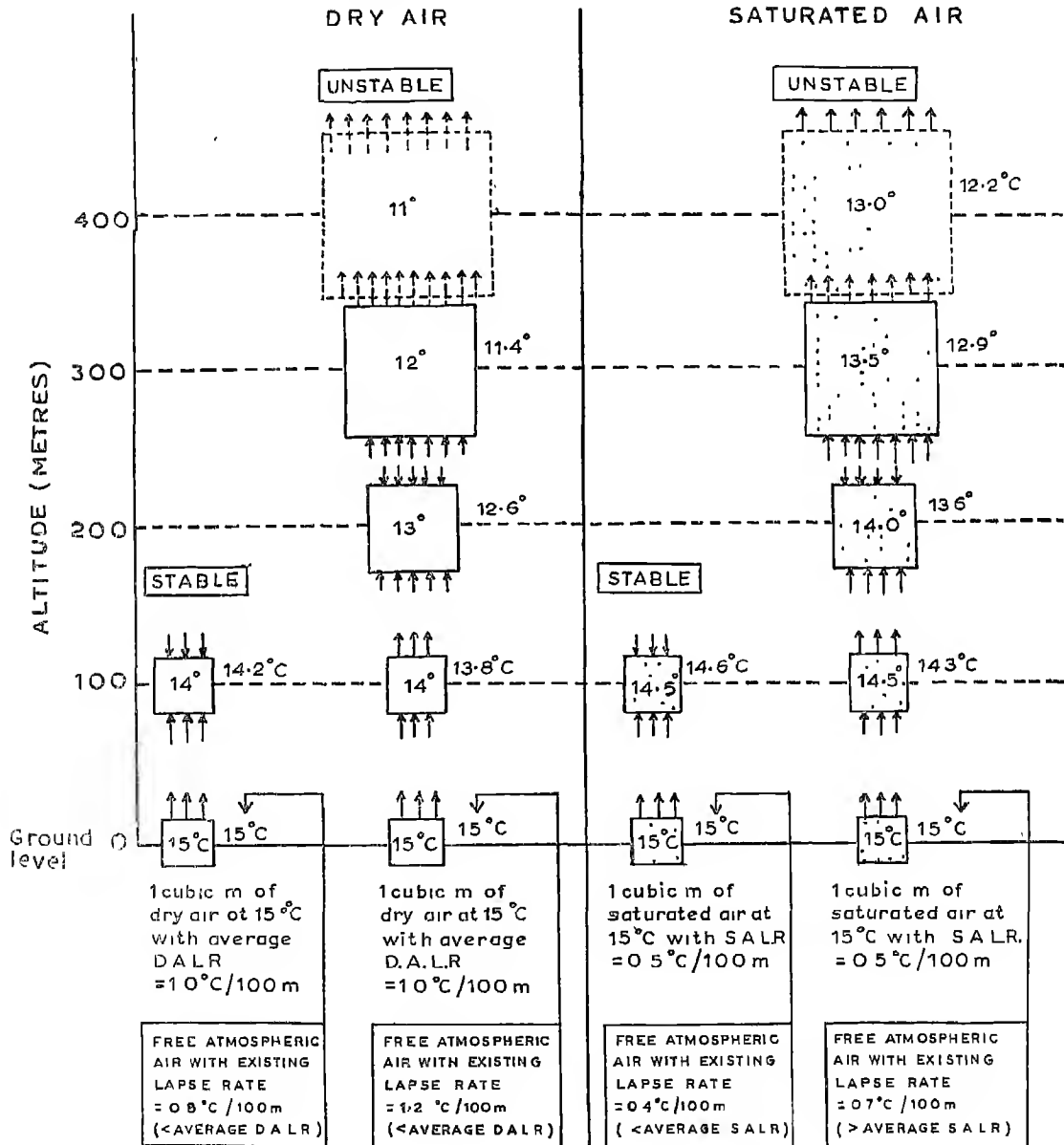
brium to a layer of the atmosphere with the help of Figure 3 14 In the first column 1 cu m of dry air at 15°C has been shown at ground level where the temperature is 15°C This parcel is adiabatically lifted to 100 m where its temperature will decrease to 14°C (15°—1°) due to the parcel having cooled at the DALR. Suppose the conditions in the atmosphere are such that at the level of 100 m, the temperature of the air is 14 2°C. Thus the parcel is cooler than its immediate surrounding, and therefore heavier than the surrounding The parcel then sinks back to its lower position. The layer of the atmosphere is in stable equilibrium The other cases illustrated in the diagram represent the dry air parcel in different existing lapse rates in the atmosphere, and there are two cases of a saturated air parcel moving up in an atmosphere with two different lapse rates

If you study the diagram very carefully you would notice that the stability or instability of a layer of the atmosphere is determined by the existing lapse rate in the layer vis-a-vis the DALR (for dry air) and SALR (for saturated air)

In an unstable layer of the atmosphere, large up-currents will be produced if it is displaced slightly. If the layer is very deep, the currents will extend to greater heights As some amount of moisture is always present, the lifted air will soon be cooled sufficiently and condensation will occur After condensation the lapse rate criteria will be those for saturated air, and the currents may continue further up, in which case clouds will form and start growing up

Those of you who have watched a thunder cloud growing must have noticed how the top of the cloud looks like a boiling mass of spherical bubbles, rapidly spreading and rising upwards The upward growth continues till the foaming appearance changes into a steel-grey colour, changing noticeably the appearance of the top of the cloud Some very special kind of measurements made inside the thunderstorms show the existence of extremely strong up-currents (30 ft/sec, sometimes as high as 90 ft/sec) In the same thunderstorm, down-currents may also exist The explanation of stability and instability given here is naturally idealized Therefore we cannot hope to explain all the complicated weather phenomena happening in the actual atmosphere However, the idea of stability and instability is a basic concept which gives a useful indication and explanation of the mechanism of many atmospheric phenomena At 'cold fronts' (coming back to the frontal system of the temperate latitudes) large up-currents are met with in the violent thunderstorms which occur there

We have said elsewhere that the presence of water vapour in the atmosphere is very important When the air containing some amount of moisture is cooled sufficiently, that is, down to its dew point, condensation occurs It is known that the presence of minute particles, called condensation nuclei, is necessary for quick condensation The mass of condensed water droplets constitutes a cloud However, if this cooling and consequent condensation has taken place near the ground surface we get a cloud formed on the ground, and we call it 'fog' Fog can also occur over the surface of the sea and of large inland waters

You can ask your teacher to show you pictures of clouds, or you can see for yourselves from a cloud atlas or a book on clouds the various forms of clouds that occur In the accompanying sketch the various cloud forms have been diagrammatically shown and explained You will notice that these forms of clouds can be grouped into two broad types The first are the layer type of clouds in which the cloud mass spreads in all directions If you see the top of these clouds from a hillock or from an aeroplane, the top surface will appear smooth, like the surface of a lake. The second type includes all clouds which show growth in the vertical direction Another way to divide clouds is to class them according to the level where the cloud occurs. In this system clouds
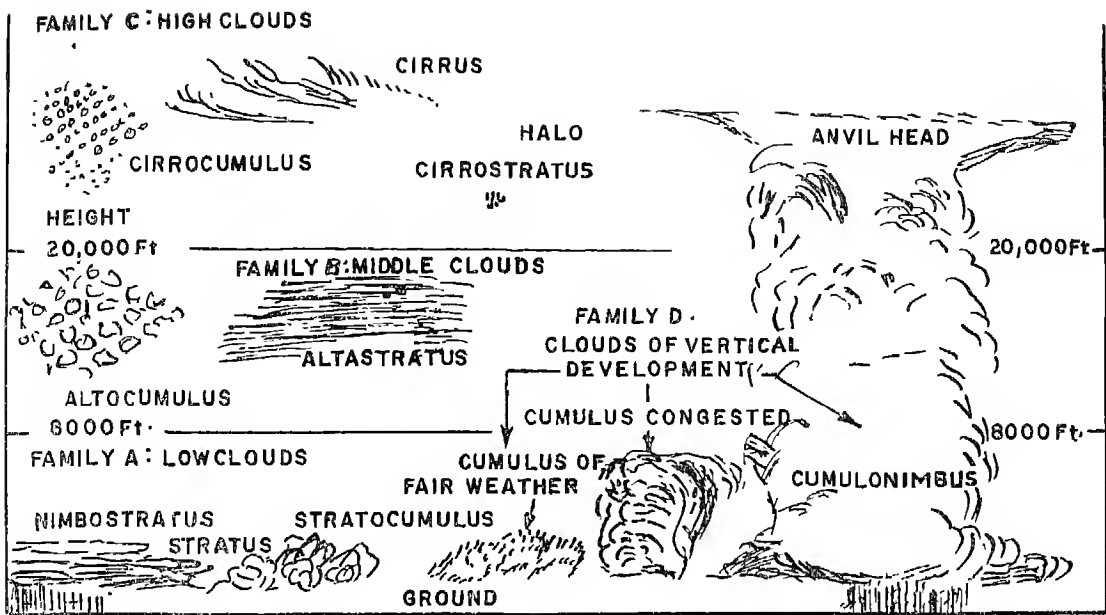
FIG. 3 15 *The various forms of clouds*

would be of types A, B, C and D as described below

A Low clouds.

B Medium clouds

C High clouds occurring at very high levels in the atmosphere, where the temperature is well below freezing temperature, such clouds consist entirely of ice crystals.

D Clouds with great vertical development; these have their base at low cloud levels and their tops at high cloud levels

Clouds consist of numerous minute droplets of water or ice, or of both As these are supported by up-currents in the air, they remain suspended However, under certain conditions which are not yet fully understood, the minute droplets grow into larger sizes when they fall as raindrops. If the intervening layer of air is very dry, the drops may evaporate before reaching the ground. Rainfall may occur in the form of sharp showers in which large raindrops are predominant, or it may be in the form of minute droplets which seem as if they are floating in the air

On the other hand, if the temperatures are very low throughout, instead of rain we get snowfall, flakes of snow gently float down in the air. In snow-storms these flakes are whipped up in a white flurry. Hail, on the other hand, is a spherical, conical or irregular pellet of ice, usually hard, and is built up by layers of opaque and transparent ice, like an onion. The size may vary from a few mm to 12 cm. Sometimes soft hail also occurs Hail is always associated with thunderclouds The onion-like structure of the hailstone is taken to indicate that the pellet has made many excursions through the region where freezing is occurring. The size of the hailstone is evidence of the strong currents which are able to carry such pellets up inside the thundercloud Yet another form in which moisture is thrown out of the atmosphere is the dew settling on grass, leaves of plants and trees. When water vapour con-

denses on these surfaces, they cool to a temperature equal to or lower than the dew-point of the air around them. In north-west India, dew forms an important source of moisture for the winter crops raised in that region.

Let us consider a few more phenomena that occur in the atmosphere and attempt to find a simple explanation for them. You might be familiar with the whirlwind, which is also known by the name 'dust devil'. The whirling wind is made visible by the dust, sand and other objects picked up from the ground. These whirlwinds occur in hot and sandy regions. Their diameters range from 10 to 1000 feet. In very hot desert regions the height may be several thousand feet, but it is generally less than 100 feet. The rotation may be in either direction round the centre. The intense heating of the ground sets up the air into a whirling vortex, whose core has a low pressure. If a medium-size whirlwind passes right over a meteorological observatory, the record of barometric pressure will show a sharp dip. Figure 3 16a shows the barograph record at Jodhpur for the 29th March, 1949, when a fairly large whirlwind passed directly over the observatory.

The cyclonic storms, about which you hear every year, are on a much larger scale and cause a lot of damage. The death and destruction caused by the cyclones are only too well known. These cyclones form in the Bay of Bengal or Arabian Sea in the latitude belt of 10° to 14°N. Cyclonic storms never form on the equator. The wind in the cyclone always blows round the storm centre, called the eye, in a counter-clockwise direction (Northern Hemisphere). The speed of the wind exceeds 34 knots over a considerable portion of the

FIG 3 16a   *Barograph record at Jodhpur for 29 March 1949*
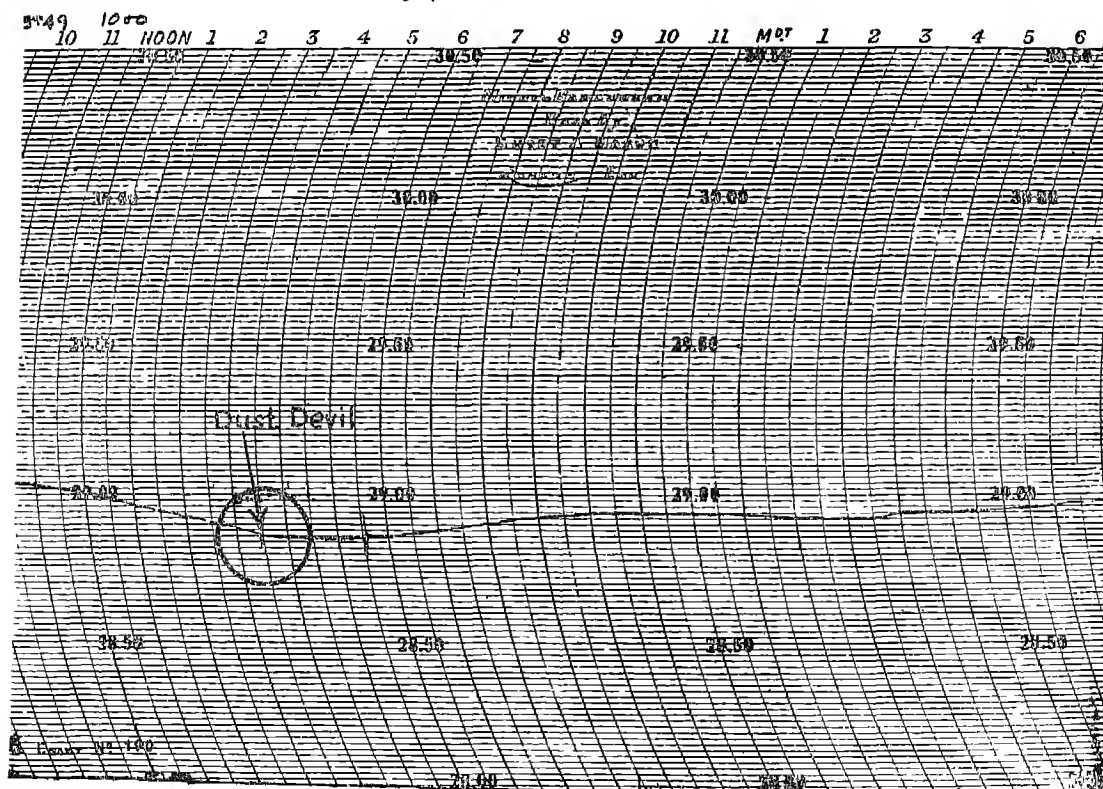
field of the cyclone The curious thing about the cyclone is its eye, the central area of 15 to 20 miles diameter, where no winds blow In this area, the sky may be clear or slightly clouded, the barometric pressure is the lowest. Round the eye is the inner ring of hurricane winds (65 knots or more), more or less circular in shape and 30 to 80 miles in diameter Violent gustiness and, often, torrential rain is found in this belt Due to the action of the strong wind, great waves are generated in the sea The outer area is not so circular but the wind continues to revolve in the counter-clockwise direction and the cloudiness and rain continues In the Bay of Bengal and Arabian Sea, cyclones occur during the months of April and May and from October to December They move initially in a north-westerly direction, then recurve north strike the coastal area, the strong wind, the rain and the waves cause havoc in the area The exact mechanism of the cyclonic storms

is not known; it is, however, generally agreed that the tremendous amount of energy involved in the cyclone is derived from the latent heat of water, and that marked instability in the atmosphere is a prerequisite for the formation of cyclones Figure 3 16b shows the barograph record of a ship which passed through a cyclonic storm in the Bay of Bengal The similarity and the differences between the two records (Figure 3 16a and 3 16b) can be clearly seen Unlike the cyclones, the so-called monsoon depressions form further north (20°N latitude) in the Bay of Bengal A few are known to have formed on land also. The wind speed in these depressions does not reach the violence of the cyclonic storms These depressions are very characteristic of the Indian monsoon and are, therefore, unique. They move in a west-north-westerly or north-westerly direction and then recurve north and north-eastwards; after further travel they often break up over the Himalayas They pass over the whole of north India, beginning from the Bay of Bengal coast, and bring a considerable amount of rainfall along their path A large amount of monsoon rainfall in many parts of the country is caused by these depressions They begin to form towards the end of June and continue through July, August and September, a few may form even in early October

The press in India, and probably in other countries also, often applies the term cyclone to weather phenomena which are not cyclones The commonest misapplication is in the case of the thunderstorms about which we have already spoken Thunderstorms occur throughout India, but some parts are more prone to it than others, for example, in north-east Assam thunderstorms occur on a hundred days in the year In their most violent form, they are the Nor'-westers (*kalbaisakhi*) of Assam, West Bengal, Bihar and Orissa The Nor'-westers are extremely violent thunder squalls and cause severe damage to even strongly built buildings and structures Big trees are uprooted and flung away by the violence of the wind Some-

Fig 3 16b *Barograph record of a ship which passed through a cyclonic storm*
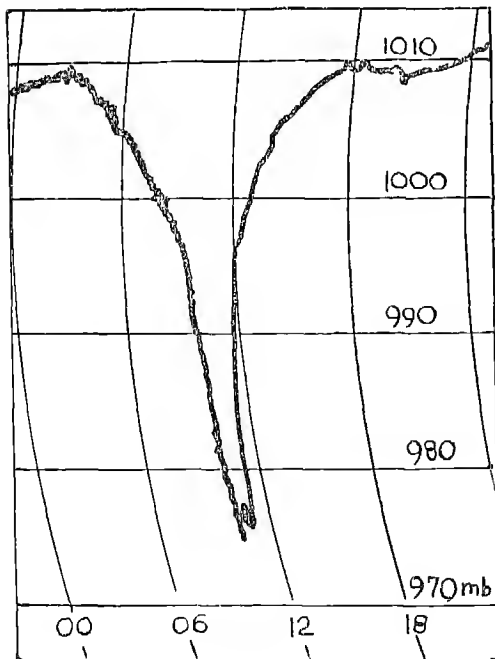
times a large amount of rain accompanies the Nor'-westers Further west, and inland, the severe storms appear as *andhi* (dust-storm) The winds here are very strong and bring huge quantities of dust and sand which are lifted to a height of several thousand metres in the atmosphere. The Nor'-wester and *andhi* are similar in their nature. In both, there is violent upturning and churning up of the atmosphere, arising out of extreme instability. In the case of the *andhi,* because of lack of moisture very little rainfall occurs, instead, dust is churned up and spread throughout the atmosphere In thunderstorms in which hailstones occur, the up-currents are violent and extend over a great depth in the atmosphere, further, there is plenty of moisture present throughout the deep layer of the atmosphere In all these storms, there is a readjustment of the air by violent upturning and churning up, started from an initially pronounced instability, and, to that extent, Nor'-westers and *andhis* are similar phenomena

The more spectacular display, however, is the lightning and thunder which accompany the thunderstorms Strokes of lightning involve electric currents of the order of thousands of amperes and require many millions of volts to strike The lightning discharge takes place between adjoining clouds, from clouds to the ground, and sometimes upwards from the top of the thunderclouds (cumulo-nimbus) to ionise layers aloft. When the lightning is seen from behind the clouds, it appears as sheet lightning The loud crack accompanying a stroke acquires its rolling character by multiple reflections and is the familiar thunder which has given the name to the storm.

The rainfall and the snowfall during the winter months over north India are caused by certain disturbances which originate as far away as the Mediterranean Sea and travel from west to east Those that travel across or near portions of north-west and north India give rise to cloudy and foggy weather with rain and snow These disturbances bear a closer relationship with those of temperate latitudes than the purely

tropical ones However, you must not conclude that the basic physical principles of the formation of cloud, rain and snow, etc , are different in the two cases

Atmospheric optics

In the cloud-free atmosphere there is a normal gradient (upwards) of density, because the temperature and pressure decrease in a regular manner with height. However, under certain circumstances, an abnormal density gradient can be found in layers of limited thickness, for example, in the air over an asphalt road under a very hot sun one may find an abnormal density gradient. As a result, light rays are refracted by the layers of different densities, they finally suffer total reflection. You must have heard of the phenomenon of the mirage, which occurs in deserts, under strong heating. Several other optical phenomena have also been observed, for example the phenomenon of 'looming', in which the horizon appears to enlarge much beyond its usual dimensions.

All of you have seen the colourful arc of the rainbow A rainbow is caused by raindrops in suspension, in passing through which rays of sunlight first suffer a refraction, which splits the light into its seven colours, then one internal reflection occurs followed by another refraction which separates the colours further If the sun, the assembly of raindrops and the eye of the observer are in a certain definite position in relation to each other, the eye sees the coloured arc of the rainbow Often, a secondary arc with its colours reversed can be seen at a small distance outside the primary arc. This is the secondary rainbow. A rainbow can also be artificially produced in dew-drops on the ground or in a spray from a fountain If the suspended particles present are ice crystals instead of water droplets, phenomena called 'halos' are shown by the sun and the moon The sun also gives rise to the 'corona' through thin layers of clouds

Lastly, in connection with atmospheric

optics, mention must be made of the aurora. This is nature's gift of beauty for the polar regions. During a great display the aurora may extend so far in the direction of the equator as to be visible in the tropics Other forms of the aurora appear with much movement and colour, the most characteristic colours being yellow-green and red, greenish 'rays'. These may cover most of the sky towards the poles, ending in an arc which is mainly folded and sometimes has a red lower border, in the latter case, the display resembles a moving 'drapery'

Synoptic meteorology

Synoptic meteorology is the study of weather as observed simultaneously at a number of places It started about a hundred years ago, in 1854, when Leverrier suggested the study of storms from meteorological observations collected from a number of places This idea was put forward by him after the French fleet met with a catastrophic disaster during a storm in the Black Sea during the Crimean War The idea quickly caught on and by the seventies of the last century most of the European countries and some others had some kind of observational network for reporting simultaneous meteorological observations. During Leverrier's time, observations were sent in by post-cards, but soon telegrams replaced the post-cards With the introduction of telegrams, various systems of codes were developed to communicate meteorological observations correctly and concisely In this direction the advance has been quite remarkable Today, a universal code is used so that exchange of meteorological observations takes place with ease among all countries of the world without

FIG. 3 17 *Synoptic chart*

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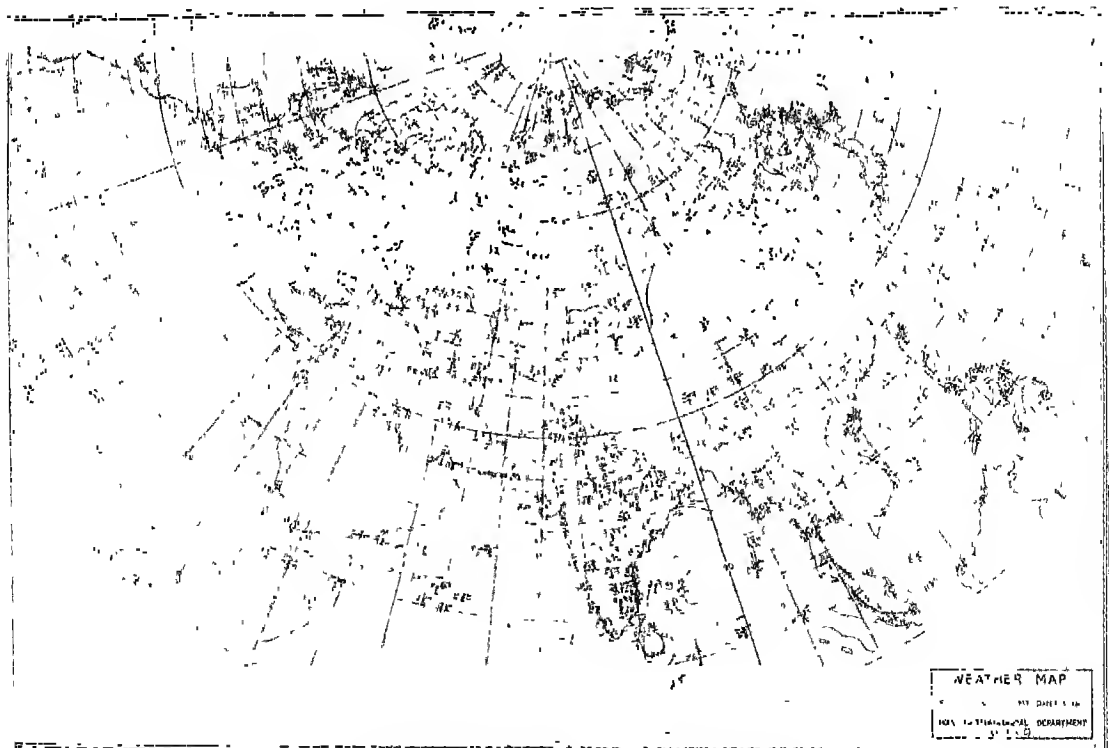
any language difficulties. The observations received in certain centres are put on suitably prepared geographical maps, using a set of symbols to represent the weather conditions as observed at a certain observatory. For example, pressure, temperature, cloud conditions (kind, amount, base and top of the clouds), and other weather phenomena occurring at the time of observation and in the past six hours, etc, have a set pattern of representation. These charts are called synoptic charts (Figure 3 17), and they form the basis of synoptic meteorology These charts are analysed, and on the basis of this analysis, synoptic charts for the future are prepared, and from these, the weather over various regions, as required, is predicted. At present synoptic charts are drawn for very extensive areas, by the meteorological centres in various countries These charts cover several adjoining continents, some centres even prepare hemispherical synoptic charts. Observations for these charts are collected from as many centres as possible. The oceans do not go completely unrepresented. For the past one hundred years or so, the merchant navy, during its voyages on the high seas, has been recording meteorological observations at fixed times of the day and night, this they have been doing as a voluntary service. These observations are collected over the wireless and used on synoptic charts Nowadays there are a number of weather ships located in the Atlantic and Pacific oceans, which record elaborate meteorological observations throughout the 24 hours. The ultimate aim is to obtain a complete coverage of the globe by establishing a network of observing points, evenly distributed over the globe, from which observations could be collected at a certain number of centres. This would constitute the 'world weather watch'. Usually several synoptic charts, numbering up to six for the different hours of the day, are plotted and analysed at meteorological offices Besides, charts are not only drawn for the surface of the earth but are also prepared for the upper levels of the atmosphere

Winds in the free atmosphere, the temperature, and the dew-point relevant to that level are plotted besides the height above sea level of the particular pressure at the points of observation. These are then analysed in the same manner as the surface synoptic charts

As already mentioned, in the last decade or so, phenomenal advances have taken place in meteorological observations, mainly due to the application of electronic aids. The electronic device employed on the radiosonde enables the meteorologist to obtain the upper air temperatures, pressure and humidity quickly. As the balloon carries the radiosonde up, its transmitter keeps on sending the meteorological data to the receiver at the ground station, so that the entire data is ready as soon as the flight of the balloon is complete In the picture (Figure 3.18) a radiosonde instrument is being sent up, tied to a large balloon Till recently, the winds at upper levels were being determined by pilot balloon observations only. In this method, a balloon filled with hydrogen gas is sent up, and its angles of elevation and azimuth are measured through a theodolite (optical) at intervals of minutes. From these records it is possible to find out the winds at the upper levels. However, with this method it is not possible to obtain the values of winds at great heights. Nowadays, at a few places in India upper winds are determined by the rawin, a method which employs radio frequency electromagnetic waves instead of the visible light rays for tracking the balloons The method is similar in principle to the pilot balloon observations; only, a much bigger balloon is used, to which a radio transmitter is attached The signals sent out by the transmitter in the balloon are followed by a radio direction-finder which gives the angles of elevation and azimuth, the same as are given by the optical theodolite, from which the upper winds can be found in the same way as by the optical method. Thus, the rawin can find the upper winds even in cloudy conditions and also up to great heights. Another important step which has increased the
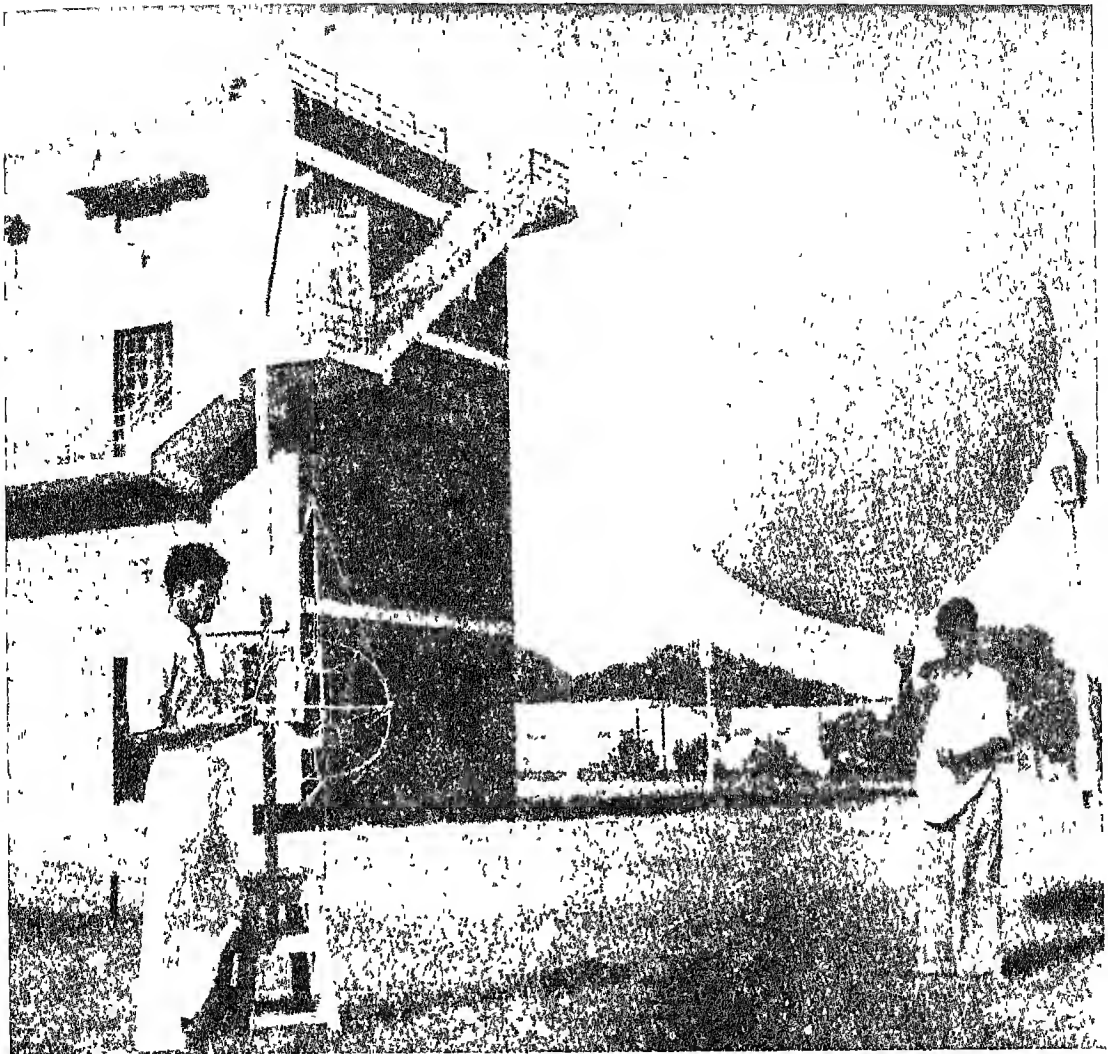
FIG. 3 18   *A radiosonde being sent up*

power and scope of meteorological observations is the meteorological radar (Figure 3 19) The radar has increased the horizon of the observer. With it, the observer can find out if there is a thunderstorm within 200 to 300 miles With some radars larger distances can be observed This radar has been used for detecting and tracking cyclonic storms. The weather radar can also detect other conditions of the atmos-phere indirectly. It has been used for finding the upper winds by tracking a balloon which goes above 30,000 metres. The meteorological radar has been used for tracking metallized nylon chaff released at heights of 30,000 metres and above by meteorological rockets. Compa-ratively, these rockets are cheap and are now beginning to be used for determining winds at 30,000 metres and above, in several countries.
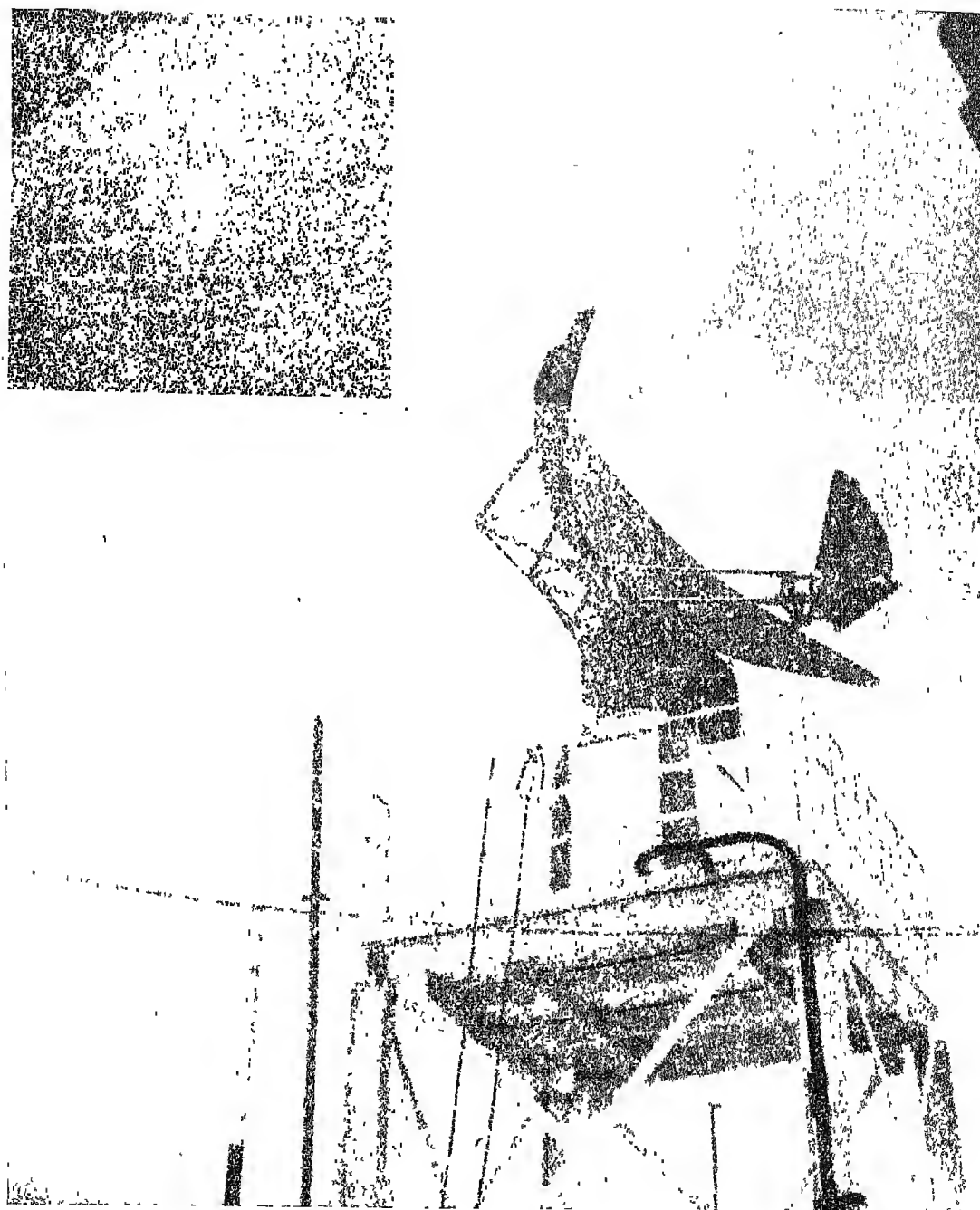
FIG. 3 19 *Meteorological radar The radar picture (inset) shows the location of thunderstorm areas within a radius of 50 nautical miles around the station. Each circular ring represents ten nautical miles*

The revolution in the methods of telecommunications in recent years has had its effect on synoptic meteorology Teleprinters and meteorological broadcasts are common in most countries Radio-teleprinters are coming into vogue For world-wide exchange of meteorological data, there is a North-Hemispheric global link by means of radio stations at New York, Frankfurt, Moscow, New Delhi and Tokyo It is quite common now to send synoptic charts from one centre to another by facsimile transmission (Figure 3 20) This is a method of sending pictures (distinct from television) from one place to another, either over wires or over radio-links
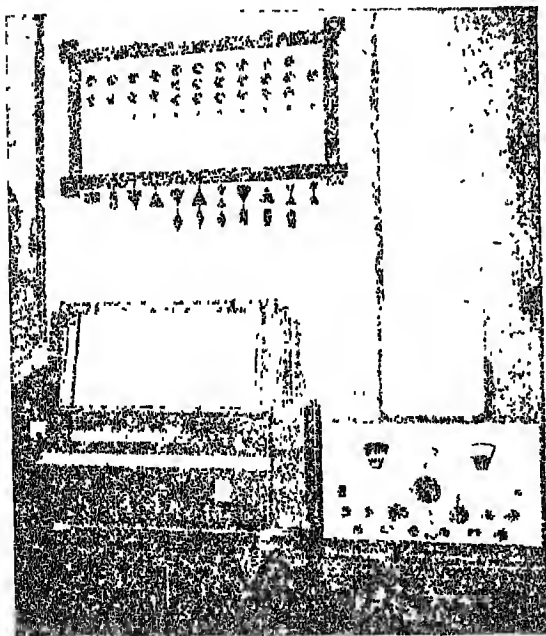
FIG 3 20 *Facsimile transmission*

The latest in the field of meteorological observation and communication is the artificial satellite The television cameras of the satellite have a grand-stand view of the clouds from a position above them Never before has such a view been obtained. Vast systems of clouds over areas which may not be well covered by surface observatories can be seen by the satellite cameras If a cyclone is beginning to grow in these areas, it can be detected well before it is picked up by other conventional means However, the satellite has a limitation if there are large layers of upper cloud, some of the incipient systems may be screened from the satellite cameras Satellites can also measure the outgoing long wave radiation and thus supply very important data which is of fundamental value in weather prediction. Figure 3.21 gives a picture of the cloud systems seen by the satellite camera of Tiros VIII. If sufficiently developed, the meteorological satellites may be an answer to the problem of the 'world weather watch'

As mentioned earlier, the analysis of the synoptic charts forms the basis of weather prediction Isobars are drawn on the synoptic charts; these isobars are lines joining places with equal atmospheric pressure After drawing the isobars, pressure systems are located; areas of rain, snow, fog, etc, are shaded and areas of pressure-rise and pressure-fall plotted on separate smaller charts In temperate latitudes, at one time it was thought that by locating these systems and tracing their movement it was possible to anticipate weather conditions, as a relic of this idea you will still find some barometers marked with the signs 'stormy', 'change' or 'fair' The difficulty is that these pressure systems weaken or strengthen with time These changes have also to be correctly anticipated by the meteorologist On the upper air charts, the flow of the wind is examined and streamlines are drawn, which enables the analyst to know how the air at different levels in the atmosphere is moving within the area covered by the analysis In present-day upper level (constant level) charts, the upper air temperatures, humidity, etc., are plotted and contour lines, showing the heights at which a particular pressure occurs, are drawn. Several other methods of analysis have been in use in the different meteorological services For instance, the idea of polar fronts,

FIG. 3.21. *Photograph taken by TIROS VIII weather satellite during its passage over the Indian area on 19 November 1964 at 0920 IST The picture shows the cloud pattern associated with a tropical cyclone in the Bay of Bengal near the Madras coast. The West coast of India, Cape Comorin and Ceylon can also be seen*

developed in Scandinavian countries, is in universal use. It considered the different air masses to be reacting with each other at 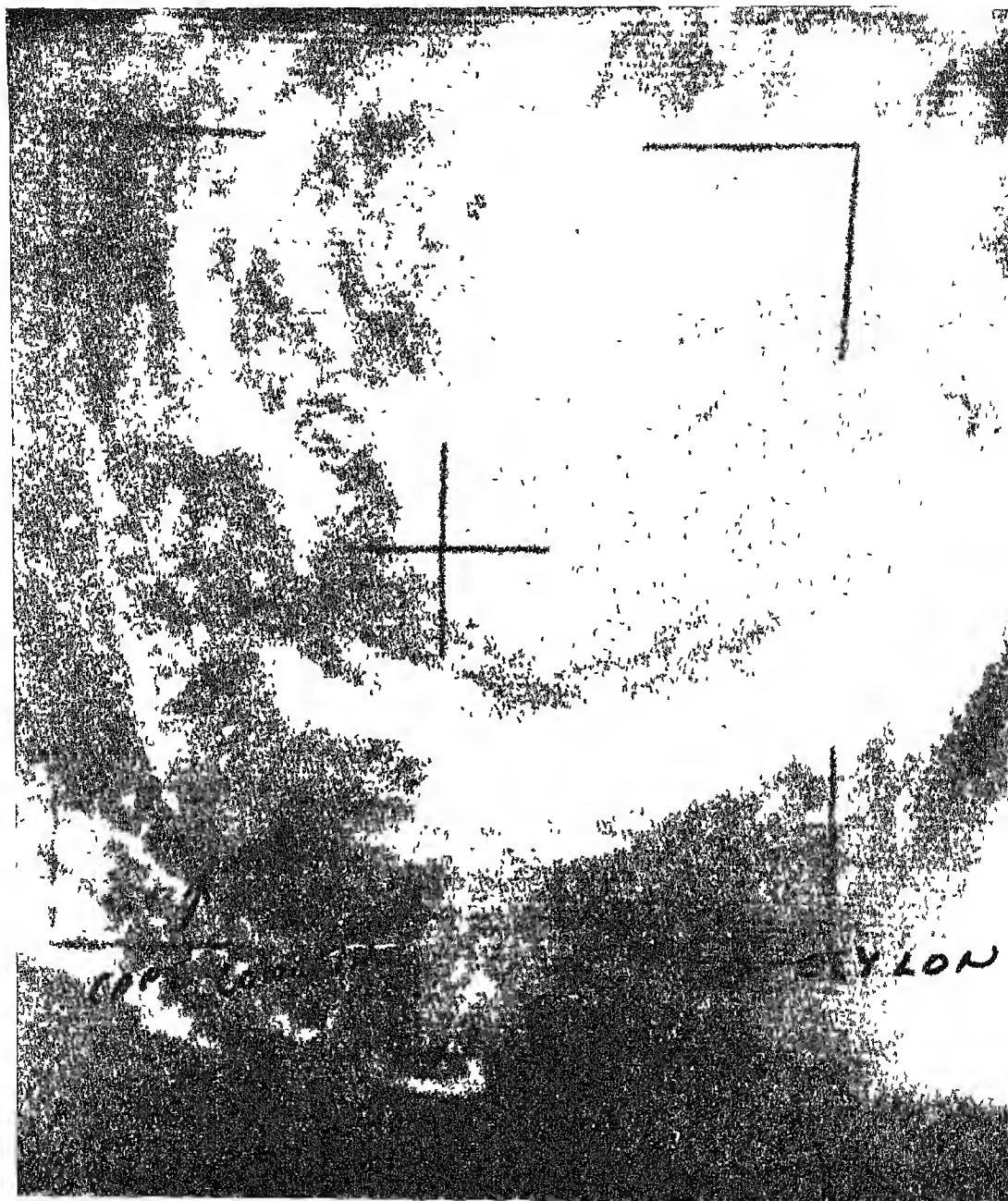their boundary regions to produce characteristic warm-frontal and cold-frontal types of weather patterns From all these analyses an attempt is made to prepare in advance the synoptic chart for a certain period of time, say 24 hours Once this chart is predicted, the weather over any area can be inferred from it. Most of the types of analysis mentioned above were worked out in temperate latitudes, but some of them have been extended to the tropics also. In the tropics, particularly on tropical islands or in mountainous regions in tropics and subtropics, the weather repeats itself from day to day with clockwork regularity A thorough knowledge of the climatology of the area is of considerable help in forecasting weather in that region. This applies to some extent to extra-tropical regions also. As yet, there exists no single standard procedure which can be followed in forecasting weather from the different types of synoptic charts in all parts of the globe. A certain amount of subjective judgement on the part of the forecaster is involved in weather forecasting.

There is a famous dictum by the French mathematician, Laplace. "The future can be completely predicted if the knowledge of the present is complete" If we apply this to the case of the atmosphere, we will say that if the present state of the atmosphere is completely known, the future states can be predicted If the present state be represented by the temperature, pressure, humidity, and the wind flow in the easterly and northerly directions and also in the vertical direction, then the values these quantities will acquire at a future moment will define the future state of the atmosphere. The ideal solution would be to calculate the future state, beginning with the present, by rigorous mathematical steps Obviously, this is an extremely difficult task During and after World War I, an attempt in this direction was made by an Englishman, L. F. Richardson, who attempted to calculate the state of the atmos-

phere at a future instant starting from the present state of the atmosphere. This work was not of immediate practical value, nevertheless, it established beyond doubt the possibility of such an approach in solving the problem of predicting the future states of the atmosphere He was faced with certain serious limitations, one was that a much smaller amount of observational data than was required to fully define the initial state of the atmosphere was then available, secondly, the greater difficulty was that the methods of calculation which he used were so long and tedious that it required, according to his own estimates, 6400 assistants to keep pace with the changing pattern of the weather. As a result his significant contribution was admired by a few and then almost forgotten by all

After World War II, electronic computers came into the field and the late Professor Van Neumann and several others were responsible for starting numerical methods of weather forecasting Here, the machines solve a set of equations which express in mathematical form the physical laws governing the behaviour of a gas like the atmosphere Owing to the complexity of these equations and the rather cumbersome methods for solving them, a 24-hour forecast may require from 1 million to 10 million elementary arithmetical operations, exclusive of other operations of rearrangement, etc. Nevertheless, since modern computing machine are capable of performing such operations at the rate of 10,000 to 100,000 per second, a 24-hour forecast can be computed in a fraction of an hour. In advanced countries electronic computers are in regular use for predicting the upper air charts which show the pattern of wind flow at 5000 ft and 30,000 ft above sea level for periods of 24 to 72 hours. These forecasts come out of the computing machine automatically in a readily usable form, virtually untouched by the human hand These electronic computers, however, predict only the synoptic charts, at present The actual weather, as we know it, at any locality has to be inferred from

the synoptic charts by professional meteoro-
logists There is a long way to go before these
calculations will tell us where rain will fall,
and at what time, or whether or not there will
be a thick fog or a thunderstorm

Application to human activities

While discussing climatic classification, it
has been mentioned in the chapter on Climato-
logy that the climatic zones are always asso-
ciated with their characteristic natural vegeta-
tion types This shows clearly that the plants in
each of these regions have adapted themselves
to the meteorological conditions characteristic
to the region Animals also show similar
characteristics typical of their natural habitat,
some of which can be reduced to the factors of
climate Man, due to his great ingenuity, arti-
ficially creates conditions more favourable for
himself than the environment would ordinarily
provide Considering the enormous range of
temperatures that it is possible to conceive, the
temperature limits within which man (and
animals) can survive is extremely limited You
already know that the human body is provided
with a most remarkable mechanism for keep-
ing its temperature constant When the out-
side air temperature goes up, the hypothalamus
directs the surface blood vessels to dilate. More
blood is shunted to the skin, where it is cooled
In this case, the skin acts like the exposed
surface of an earthen water pitcher (*surahi*)
Additional body heat can be dissipated into the
atmosphere by the evaporation of perspiration,
which is a cooling process. If the atmosphere
already contains large amounts of moisture, that
is, the humidity of the air is high and there is no
movement of the air past the body, evaporation
of perspiration is retarded and the body cannot
dissipate heat into the atmosphere. This is the
reason why we feel so uncomfortable on a
muggy day The opposite effect occurs when the
weather gets colder. Blood vessels contract and
the blood supply grows less Our skin glands
dry up, and instead of perspiring, we shiver.
Thus shivering, like any other body exercise,

releases energy stored in our body fat and thus
helps to maintain our precious body heat

Both the heating and cooling processes of
the body require the expenditure of a consider-
able amount of energy. Under a really hot
summer sky, the body must work hard to
maintain its normal temperature, that is why
in the summer we are lazy and feel distressed,
and it takes all our energy to avoid becoming
overheated You will thus realize that in
designing a comfortable house one must have
a knowledge of the temperature, humidity,
wind flow, sunshine, etc, of the area, that is,
we must have climatological data before we
start designing Likewise, in designing a town
our knowledge of the temperatures, the range
of variation of these, the wind flow and its
direction, and rainfall and various other
meteorological data must be taken into ac-
count For outdoor activity, like sports, etc., a
knowledge of the climate of the place is very
helpful For designing more elaborate struc-
tures like factories, roads and railway bridges,
docks and harbours, aerodromes, etc., full
climatological data is absolutely essential, other-
wise the design can turn out to be inefficient
and even disastrous We must have a knowledge
of the strongest wind velocity in a locality and
of how often it occurs, to be able to decide how
strongly the walls of a factory or a house
should be built.

We mentioned natural vegetation a little
while ago The weather factor is equally vital
throughout the entire life cycle of crops For
this, knowledge of the rainfall—how it is distri-
buted, how reliable it is—and also of other
meteorological elements is essential. Investi-
gations have been undertaken to find out
the relation between crop growth and the
weather, and well established results are now
made available to farmers During the period
of growth of the crop, meteorological services
are required by the farmers. For instance, in
India, special weather bulletins for farmers are
broadcast and widely distributed through other
means of communication; these give an idea of

the weather, rainfall, etc, to be expected in the coming four days Further, there are certain weather phenomena which are very harmful for the crops, such as hailstorms, frost, very heavy rainfall, etc If timely warning is given some remedial action is at times possible Such warnings to farmers against specified phenomena are issued by most meteorological services Besides, reliable statistics of such occurrences are useful for insurance schemes and claims The irrigation requirement of particular crops in any area can be judged on the basis of accurate data regarding rainfall, temperature, evaporation, etc, and the meteorological service can be called upon to supply such data Thus agriculture, in its numerous aspects, requires meteorological information and service

In most countries today the meteorological service of the country supplies to the public, weather forecasts valid for different periods, say 12, 24 or 48 hours, and for different areas such as the cities and the immediate environs, and other conveniently and rationally demarcable portions of the country By using synoptic meteorology, the forecasting offices prepare synoptic charts up to six times a day On the basis of the analyses of these charts and through a knowledge of the climatology of the area and certain inferences on theoretical consideration, and possibly through certain objective methods, forecasts of weather for the next 24 or 36 hours are prepared. These may be made to be valid for a portion of the city or town or for certain portions of the country, which may be considered to be sufficiently homogenous to be covered as one unit. Forecasts mention the chances of occurrence of rain, fog, thunderstorms, etc, and try to meet all kinds of requirements ranging from someone's problem of deciding 'whether to take the raincoat to school or not' to an ice-cream vendor's question, 'How much ice-cream should I make today'? These forecasts are distributed to the public over the radio (over the television in prosperous countries) and newspapers and sometimes through

telegrams When catastrophic weather phenomena such as cyclones are located or anticipated from the synoptic charts, quick and decisive action has to be taken by the forecasting office to warn the people of the area concerned Special warning messages are sent over the broadcasting system, telegrams are sent to various officials on the warning list. In case of cyclonic storms local officials, on receipt of warning by telegram, publicize the same by beat of drum. In small coastal ports, cyclone warning signals are hoisted to tell the people about the impending danger. In cases of forecast of very heavy rainfall, the railway authorities of the area are warned to take necessary precautions for the running of trains The forecasts issued at present are for periods of 24, 36 or 48 hours at the most Forecasts for longer periods would be more valuable for the purposes of planning. Besides, if these could be issued a considerable time before the commencement of the period for which they are valid, their usefulness would increase a great deal. On the other hand, the technical difficulties in the way of preparing such forecasts are very great, hence it will be quite a long time before such forecasts would be possible anywhere in the world

In the field of transportation, the meteorological services rendered are the greatest Since more than a hundred years, sailors have been greatly interested in meteorological studies Nowadays ships keep in contact with land by wireless during their voyage, and the regular meteorological bulletins are passed on to them The ships, too, record meteorological observations, which they pass on to the land stations. Nowadays large ocean liners decide their voyage after studying the weather charts and alter their course to avoid bad weather

On land, the condition of the road, particularly the bridges, under very heavy rain, heavy snow, or frost, etc, is extremely vital to road users Information about these is a necessary service, especially in countries where the roads have heavy traffic

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But it is for aviation that the meteorological requirements are the most exacting The meteorological conditions near the ground are important at the time of take off and landing of the aircraft, while the conditions at the level where it flies are important during the rest of the flight. Besides, the weather must be carefully observed, so that any serious deterioration or improvement in the weather conditions is immediately communicated to the aviation personnel The warning service for aviation must be very alert and efficient Forecasts are issued for every flight and are explained to the crew of the plane at their briefing These forecasts include the temperature and wind at different levels along the route, and the cloud, visibility and weather conditions to be expected during the flight You will get an idea about the amount of service rendered from the fact that during the year 1960 the forecasting offices of the Indian Meteorological Department supplied nearly 3,00,000 flight forecasts to civil pilots In planning the air routes during the various seasons, the upper air climatological data is utilized to decide how to fly most economically, and at what height; what times to choose to give the maximum comfort to passengers, etc

For military flying the requirements are so heavy and varied that these authorities have their own meteorological service

You know that many parts of our country are affected by floods every year These are mainly caused by exceptionally heavy rainfall in the catchment areas of a large number of rivers, especially those rising from the mountains. In order to mitigate these floods many flood control projects have been undertaken and several of them completed Fortunately, these combine hydroelectric power generation with flood control In designing these projects, accu-

rate meteorological data covering a large number of years have to be examined very carefully What is the rainfall in the catchment area and in its different parts? What is the heaviest rainfall, how widely is it distributed, and how often does it occur? How great is the rate of rainfall? Hundreds of such questions arise. In answering these, accurate climatological data is required. After the design has been decided upon and the project completed, meteorological information about rainfall and its intensity is required for operating the projects from day to day Further, forecasting of whether, particularly rainfall, is very necessary during the operation of the project for the purpose of flood control and power generation.

The few examples given above show how meteorology impinges on many aspects of our lives The aim is to have a complete understanding of all the phenomena that are occurring in the atmosphere through its entire depth. It is not enough to have a qualitative understanding. Ultimately, we must be able to calculate the magnitude of all the quantities involved Only then will the anticipation of the future weather with absolute accuracy be possible If this is achieved, we may be able to control the weather Some day we may be able to maintain the temperature and the humidity of the air at desired values, and the wind speed at the desired speed from a definite direction; and the sunshine may be ordered for definite periods over fairly large, open tracts of the country. Harmful weather phenomena like hailstorms and hurricanes may be dissipated before they mature or reach areas where their destructive effects may cause great damage to life and property. That day is still far away; our task is to understand in greater and greater detail the science of meteorology

Minerals

The solid earth on which we live consists of many types of rocks formed during different geological eras This entire region of rocks is called the lithosphere (sphere of rocks) Even a single boulder may contain different kinds of rocks. Each type of rock, like granite, basalt, sandstone, or marble, may contain one or more minerals.

Minerals are inorganic substances generally formed by inorganic processes such as solidification from molten material, crystallization from solution or mechanical deposition from suspension in water. Some minerals may be formed through the agency of organisms—calcite, aragonite, apatite in molluscan shells and silica in the skeletal remains of diatoms.

Minerals are built up of elements Some minerals contain only one element, for example, gold, copper, platinum, sulphur and carbon (as diamond and graphite) Some are simple compounds of two elements, like oxides (quartz, rutile, hematite, magnetite, cassiterite), sulphides (pyrite, sphalerite, galena, stibnite) and chlorides (halite, sylvite) Several are simple salts of a metal and a non-metal, like sulphates, carbonates, nitrates, phosphates and arsenates Some others are double salts like sulpharsenides and sulphantimonides Five elements—oxygen, silicon, aluminium, iron and calcium—make up 90 per cent of the earth's crust, up to a depth of 15 km. Another seven elements, sodium, hydrogen, potassium, magnesium, titanium, carbon and chlorine constitute 9 per cent of the earth's

Fig 4 1

crust up to a depth of 15 km Their occurrence is given in the following table

TABLE 4.1

THE MAJOR ELEMENTS IN THE EARTH'S CRUST

	Weight (per cent)		Weight (per cent)
Oxygen	49 5	Potassium	2 4
Silicon	25 7	Magnesium	1 9
Iron	4 7	Titanium	0.6
Aluminium	7 5	Hydrogen	0 9
Calcium	3 4	Chlorine	0 2
Sodium	2 6	Phosphorus	0 1

A very important and numerous class of minerals are the silicates

Minerals possess certain definite geometric forms resulting from the arrangement of the elements in symmetric patterns These forms are called crystals and have smooth faces meeting in straight sharp edges The crystalline forms can be put into 6 major groups called systems—cubic, tetragonal, hexagonal, orthorhombic, monoclinic and triclinic (See Ch. 1)

Perfect crystals are rare in nature. But they do form under very favourable conditions from a slowly cooling molten magma or from solution in a cavity. Some examples are · beryl, mica, feldspar, zircon, garnet, calcite, gypsum, etc

Minerals may be contaminated by impurities These may be due to extraneous elements in the crystal structure itself (e g , magnesium or iron in calcite, titanium in magnetite) or may be tiny inclusions which may be hair-like, platy, granular, fibrous or coarse

Minerals show various structures and textures depending upon their intrinsic nature and conditions of formation Some are granular and form compact aggregates, like those in granite. Some are flat and platy, like mica Others are fibrous, like asbestos and gypsum Some occur as coarse grains or lumps and others as fine grains Granite and limestone are common rocks showing a great variety of grain size Some limestones (e g , lithographic stone) and quartzites are so fine in texture that the individual grains can be made out only under magnification

Physical properties

Minerals can be identified by certain ordinary physical characteristics, optical and X-ray characteristics and also by their chemical composition We are concerned here with simple physical properties These are · colour, streak, lustre, specific gravity, hardness, cleavage and fracture.

Colour Minerals display a great variety of colours Some have a characteristic colour, e.g , malachite, deep green; azurite, bright blue, hematite, deep brownish red, pyrolusite, dull black Others may show different colours depending on composition, impurities and mode of formation. Corundum is ordinarily opaque and grey but transparent corundum having different colours is called by different names (sapphire—blue, ruby—red, oriental emerald—green, oriental topaz—yellow, etc) Similarly, spinel and tourmaline exhibit various colours Ordinary beryl varies from opaque white to dirty green, but when it is transparent and light blue, it is called aquamarine; and when the colour is a bright green, it is called emerald Minerals which are comparatively rare, hard, transparent and coloured are classified as the precious stones, while those which are fairly common, hard and opaque are the semi-precious stones

Streak This is the colour of the streak of powder left on a matt white surface when a mineral is drawn across it (or when it is finely powdered). The streak can reveal the shades of a colour nicely and is therefore useful, especially as some minerals give a colour in the streak, which appears different from the colour in the mass Thus hematite, whether it looks brown or black, gives a dark red streak; limonite gives a yellowish brown streak; and pyrite, a black streak tinged with yellow

Lustre. This is the peculiarity which may be called the appearance of the mineral, apart from

its colour The surface of the mineral reflects light in a particular way which may be called earthy, dull, pearly, silky, waxy, glassy, metallic, steely, splendent, etc

Specific Gravity This is the ratio of the weight of a given piece of material compared with that of an equal volume of water In some cases, when similar looking substances are handled, we can tell the difference by 'feeling the weight' Thus we can tell readily the difference between calcite (sp. gr = 2 71) and barite (sp gr = 4 4) In many cases, however, it would be necessary to determine the specific gravity reasonably accurately This may be particularly useful in identifying certain gem minerals, though other confirmatory tests will have to be conducted.

Hardness Hardness is the property of resisting abrasion It is ordinarily determined by observing the ease with which one mineral can be scratched by a sharp fragment of another or by the steel blade of a pocket-knife As there is a wide range of hardness, certain minerals are used as standards on a scale called the *Moh's Scale of Hardness* This scale is given below

Scale	Mineral	Hardness
1	*Talc*	Very soft and feels greasy between the fingers, can be rubbed off very easily
2	*Gypsum*	Can be scratched by the finger-nail
3	*Calcite*	Readily cut by a knife blade, but just scratched by copper or bronze.
4	*Fluorite*	Easily scratched by knife blade.
5	*Apatite*	Scratched with some difficulty by knife blade but easily by a file.
6	*Orthoclase*	About as hard as a steel blade but can just be scratched by a file. This mineral can scratch ordinary glass.
7	*Quartz*	Harder than a knife blade, scarcely scratched by a file
8	*Topaz*	Scratches glass very readily, and quartz easily
9	*Corundum*	Scratches most other substances
10	*Diamond*	The hardest substance known It is even harder than the artificial abrasives [1]

Most minerals are softer than quartz, i e., scale 7 in hardness Only a few (several being alumino-silicates) are harder and the chief gem minerals are amongst these

Cleavage and Fracture Cleavage is the property of a mineral to split easily along certain directions which are determined by the molecular structure. Mica and talc have excellent cleavage Calcite and gypsum have good cleavage Diamond has also good cleavage and is easily split along particular directions for reducing the size or for eliminating portions with flaws and inclusions

Fracture is the natural appearance and nature of a broken surface Some minerals break with a glass-like or shell-like (conchoidal) fracture, some with irregular uneven surfaces, some with a splintery fracture, and some with harsh and sharp projections (hackly fracture)

Other Properties Some minerals, containing radioactive elements like uranium or thorium, are readily detected by a suitable apparatus like the Geiger counter which can detect the radiations given off. About one hundred radioactive minerals are known, but they are not very common

Some minerals glow in the dark after exposure to an ultra-violet light beam (wave length in the range of 1600 to 3800 Angstrom units) There is often a play of brilliant colours. Some of the minerals possessing this property are·

[1] Recently, boron nitride, an artificial abrasive, has been produced, this is harder than diamond

fluorite (calcium fluoride), willemite (zinc silicate), scheelite (calcium tungstate), wernerite (a silicate of calcium, etc), sphalerite (zinc sulphide), and most uranium minerals This *fluorescent* - *property* may also be shown by several ordinary minerals' which contain some uranium as impurity (e.g , some limestones)

Rock forming minerals

Minerals may be classified into *rock forming* and *economic*. The rock forming minerals are the most common and are the main constituents of rocks The major rock forming minerals are listed in Table 4 2 Economic minerals are those that are used for industrial and other purposes.

TABLE 4.2

COMMON MINERALS IN THE EARTH'S CRUST
(IN PER CENT)

Mineral	Lithosphere	Igneous rocks	Sedimentary rocks
Feldspar	49	50	16
Quartz	21	21	35
Pyroxene, amphibole, olivine	15	17	
Mica	8	8	15
Magnetite	3	3	
Titanite and ilmenite	1	1	
Others	3		3
Kaolin (clay)			9
Dolomite			9
Chlorite			5
Calcite			4
Limonite			4
	100	100	100

The most important rock forming minerals are quartz, orthoclase (K-feldspar), plagioclase (Na- Ca feldspar), amphiboles, pyroxenes, olivine, nepheline, muscovite, biotite, calcite, dolomite, hematite, magnetite, kaolin and other clay minerals. • Garnet, chlorite, talc, apatite, zircon and tourmaline are some of the less important rock forming minerals. Each major rock type

has certain characteristic or essential minerals. The rock type may be subdivided by making use of the relative abundance of the minerals present.

Quartz. It is one of the most common minerals and is composed entirely of SiO_2. It commonly occurs in a granular form Crystals when found are hexagonal, with pyramidal terminations. Its hardness is 7, and its specific gravity is 2 65 Transparent crystals are colourless Opaque crystals and granular material may be white, pink, yellow, brown, green or black Transparent crystals of a particular type are cut into thin plates and used in radio and television because of the mineral's piezo-electric property by which any pressure put on the crystal generates a minute electric charge Quartz crystals are also used for making lenses and prisms for optical instruments Quartz can be molten and made into glassware for the laboratory.

Chalcedony This exceedingly fine-grained quartz is often coloured variously It is sometimes beautifully banded if the solution is deposited in the cavity of a rock, the material formed is called *agate* Agate and chalcedony are semi-precious stones and are made into beads for necklaces, trinkets and artistic objects

Feldspars The feldspars are the most abundant minerals in nature and are found in nearly all igneous rocks. The chief species are *orthoclase, microcline* and *plagioclase*. All have very similar crystal forms and show good cleavage (close to 60° and 120°) They have a pearly lustre and have a specific gravity of about 2 6 Orthoclase and microcline are alumino-silicates of potassium ($K_2O\ Al_2O_3\ 6SiO_2$), while the plagioclases are homogeneous mixtures of sodium and calcium alumino-silicates ($Na_2O\ Al_2O_3\ 6SiO_2$ is called albite, and $CaO\ Al_2O_3\ 2SiO_2$ is called anorthite)

Amphiboles These are complex hydrous silicates of calcium, magnesium and iron The crystals are long and needle-like, or even fibrous. In thin sections they show cleavages making angles very near to 55° and 125° Their

colour varies from a light to dark green. Their hardness is 5 to 6, and specific gravity is 3 4

The following are the more common amphiboles amongst the numerous species known.

Tremolite: $Ca_2Mg_5(OH)_2(Si_4O_{11})_2$
Actinolite: $Ca_2(Mg, Fe)_5(OH)_2(Si_4O_{11})_2$
Hornblende. Complex hydrous silicate of Ca, Mg, Fe, Mn, Al, K, Na

Pyroxenes. These are similar in composition to the amphiboles but do not contain the hydroxyl They occur as short stumpy crystals with cleavage angles near 90°, but occasionally they are long and needle-like They also show shades of green colour Their hardness is 5 to 6, and the specific gravity is 3 4 to 3 6 The more common species are:

Enstatite: $MgSiO_3$
Hypersthene (Fe, Mg)SiO_3
Augite. Ca, Mg, $(SiO_3)_2$ with (Mg, Fe) (Al, Fe)$_2SiO_6$

The gem mineral, jade or jadeite Na Al $(SiO_3)_2$, belongs to this group

Micas This family of minerals has perfect basal cleavage They are hydrous alumino-silicates of alkali and other metals They form large six-sided crystals Their hardness is 2 5 to 3 and specific gravity is 2 8 to 2 9 The common micas are:

Muscovite (K. mica) This is white or light green.
Lepidolite (Li. mica) This is white or sometimes pinkish
Phlogopite (Mg. Mica) This is yellow to orange
Biotite (Mg, Fe mica) This is black

Olivine. This is a group of minerals, ordinarily green in colour The common olivine is an orthosilicate of Mg and Fe—(Mg, Fe)$_2SiO_4$ Other species contain Ca, Mn, Fe, Mg, in various combinations (H = 6 5 to 7, Sp Gr = around 3 3) They are found in igneous rocks which are rich in magnesium and low in silica, or in metamorphosed limestones and dolomites

Garnets This is another family of minerals found in igneous and metamorphic rocks. They crystallize in the isometric (cubic) system and are often found as good dodecahedral or trapezohedral crystals The chemical composition is of the type $R_3'R_2''(SiO_4)_3$ in which R' is Ca, Mg, Fe, Mn, and R'' is Al, Fe, Cr, Ti The most common garnet is the red to purple coloured almandite $Fe_3Al_2(SiO_4)_3$ Garnets are also found in other colours, depending on the composition. Their hardness is 7 to 7 5 and the specific gravity is 3 4 to 4 3.

Chlorite. It is a small group of hydrous iron, magnesium and aluminium silicates. It is a product of the alteration of other ferro-magnesium minerals and occurs in small granular or sheaf-like bunches of green colour This group possesses good mica-like cleavage, but the flakes are crumpled, being inelastic Its hardness is 2 to 2 5, and the specific gravity is 2 6 to 2 8

Talc or *Steatite* It is a magnesium silicate $(Mg_3Si_4O_{10}(OH)_2)$ found as masses, bands or flakes in metamorphosed dolomites or basic igneous rocks. It is white, light green or grey in colour Its hardness is 1 to 1 5 and its specific gravity is 2.75 The mineral has a good micaceous cleavage but the flakes are inelastic It is very soft and is often used for making objects of art, statues, etc.

Serpentine This is a hydrous magnesium silicate ($H_4Mg_3Si_2O_9$ or 3 MgO, 2 SiO_2 2 H_2O). It is white, creamy or green to black colour. It is formed from magnesian igneous rocks or from dolomite by metamorphism. Its hardness is around 3, and specific gravity, 2 6. When occurring in large masses, it can be cut into blocks for use as an ornamental building stone, or made into vases, trinkets, etc The fine fibrous form is called 'chrysotile asbestos'

Epidote This is a group of hydrous alumino-silicates with Ca, Fe, Mn, etc, found in metamorphic rocks and in some granites The common epidote is green in colour and forms slender prismatic crystals Its hardness is 6 to 7 and its specific gravity is 3 3 It is sometimes found as radiating clusters of needle-like crystals in metamorphosed limestones

Tourmaline It is an alumino-silicate of certain metals (iron, calcium, magnesium and alkalies) containing some boron, and occurs in some granites and schist. It forms stout, six-sided black crystals often with longitudinal striations on the prismatic faces Its hardness is 7, and its specific gravity is 3. Some transparent tourmalines are coloured pink or green and are used as gemstones

Economic minerals

Economic minerals include a large number used for a variety of purposes. Those which are used for the extraction of metals are called *ores* Other minerals may be used as abrasives (for grinding and polishing), as refractories (heat resisting materials) for the manufacture of glass, ceramics, paints and pigments, as gemstones and as raw materials for the chemical industries

In their natural state, the useful ore minerals are mixed with a lot of useless material called gangue. The quality of the material (percentage of the metal or useful constituent) is known as the grade, which may be described as high, medium or low according to the profitability of working it. This, however, will depend on a number of factors

The location of a deposit with reference to accessibility and transport is an important factor A deposit close to a good road or railway is less expensive to work than one in the interior where there are no transport or other facilities like water, power and labour supply. Cheap transport and nearness to markets are also important. Road transport is costlier than rail transport, and this, again, is costlier than water (sea or canal) transport.

The nature of the deposit has great influence on the method and cost of working. A deposit exposed at the surface or at shallow depth with a simple geological structure is easier and cheaper to work than the one at some depth with a complicated structure The amount and nature of the impurities associated with the useful mineral are of importance as they deter-

mine the type and cost of the processes to be used in the recovery of the useful materials

Developing and working mineral deposits

Mineral deposits are formed in nature under specific conditions Some are found in igneous rocks, either as constituents of the rocks themselves or introduced by the igneous emanations Some minerals are deposited with sedimentary rocks Some are formed as surface accumulation, as a result of weathering of the rocks; or these residues may get concentrated along streams or beaches

Igneous Deposits Many metalliferous minerals are closely connected with igneous rocks and are derived from them. But only a few solidify as part of the igneous masses Some examples are: chromite, titaniferous magnetite and apatite masses in basic rocks, cassiterite and wolfram in granites, feldspar, mica and beryl in pegmatite, and copper sulphide minerals in porphyry

Hydrothermal Deposits Many minerals, particularly those of the useful metals, are transported by water in the gaseous or liquid state and deposited in the fracture and shear zones of existing rocks (igneous, sedimentary or metamorphic) These generally form veins and lodes. Different minerals form under different ranges of temperature and pressure, gold, arsenopyrite, cassiterite and wolfram at high temperature, copper, nickel, cobalt, and molybdenum minerals mainly at medium temperatures, lead, zinc, and silver at low temperatures

Replacement Deposits These are due to the deposition of minerals from solutions in partial or full replacement of the host rocks These are mainly sulphides and carbonates Though most rocks are easily replaced, the most common host rocks are limestones and dolomites The solutions enter through the major fracture zones and replace the rock on either side and very often permeate the rock to some distance laterally, depositing gradually diminishing amounts away from the main channel The soaking by the solutions produces disseminated material in the

host rock Hydrothermal deposits are, in many cases, also replacement deposits

Sedimentary Deposits These are formed by deposition, in bodies of water, of material brought in suspension or solution by rivers and streams Some examples are · beds of hematite, limonite (bog iron ore), manganese ore; limestone, dolomite, sand and clay, possibly copper sulphide and oxide of the *kupferschiefer* type found in Germany.

The following are formed from evaporating bodies of water · dolomite, gypsum, rock salt, sulphates and chlorides, and potassium and magnesium. These go under the general name of *evaporites.*

Coal and lignite beds are sedimentary deposits Petroleum is derived from organic matter deposited with sediments and it accumulates in structurally suitable porous horizons

Residual Deposits These are deposits of materials left behind after the weathering of rock masses, when some of the constituents are carried away in solution Bauxite, laterite and hydroxides of iron and manganese are formed in this manner

Some minerals highly resistant to weathering are also concentrated by such a process The mineral grains may be carried by currents of water and deposited in river valleys and beaches Deposits of this type contain gold, garnet, monazite, ilmenite, magnetite, diamonds and some of the precious stones.

Exploration, prospecting and exploitation

Mineral deposits may be discovered by chance, as they were about a century and a half ago. However, as the principles of their occurrence became better known, discovery became a matter of intelligent search Now, geologists and prospectors use scientific principles. The geological map of a territory gives a clue to the type of mineral deposit that may be present there and rules out the occurrence of certain minerals. Many metalliferous deposits occur only in regions of former mountain-building activity, because the great disturbance

of the earth's crust in those regions has enabled mineral-bearing igneous emanations to come up from below

When the presence of a mineral deposit becomes known from surface indications, prospecting is undertaken to prove its extension on the surface and at depth, and to find out its structure and peculiarities The geological structure of the formations is studied to determine the direction in which the deposit may continue In the case of shallow deposits, *pits* and *trenches* are dug along the indicated directions Wherever the deposit is met with, samples are taken systematically for analysis

When a deposit is suspected to be hidden at some depth below the surface, *geophysical methods* may be used These comprise the application of physical principles to the detection of the presence of suitable structures or of the presence of certain types of minerals The *gravitational method* is used to discover differences in the relative density, so that a dense mass surrounded by more ordinary rocks is easily delineated A large lode of metallic sulphide or a large lens of chromite or magnetite can be detected in this manner

Magnetic Prospecting The presence of a body of high magnetic susceptibility can be mapped by measuring the vertical and horizontal magnetic forces over the area Bodies of magnetite and some types of manganese ore or nickel-bearing sulphides can be found by this method.

Electrical Methods of Prospecting. These methods employ the principle that certain minerals like graphite and sulphides generate an electrical field in and around them By measuring the electrical potentials at the various points in the area containing such deposits, it is possible to delineate the body Water-bearing strata can also be found by measuring the conductivity over the area, because underground water always contains dissolved salts which are electrolytes and, therefore, have greater conductivity than the adjoining strata or ground which contain very little water.

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Seismic Prospecting. This method of prospecting makes use of artificial explosions inside a borehole at a depth of a few tens of metres The explosion produce elastic waves whose refraction along certain strata, or reflections from the contact surfaces between pairs of strata, are recorded on photographic films after suitable amplification By measuring the travel time of the different refracted or reflected waves, the structure of the strata underground can be accurately depicted, and the possibility of the existence of petroleum reservoirs can be assessed This method is also useful for the study of underground geological structure and for locating any mineral deposits which may be associated with such structures

Methods for Detecting Radioactivity There are methods for detecting the radioactivity of the ground, and hence the presence of radioactive minerals The Geiger counter can detect the presence of such minerals near the surface, but the scintillometer is more powerful and can be used from helicopters or aeroplanes flying over the area suspected to contain radioactive deposits at shallow depths

Geochemical Methods These have come into use more recently For this purpose, soil samples are taken from an area, at closely spaced intervals, and analyzed rapidly for particular elements The distribution pattern of the element will indicate the limited area to be investigated or the direction towards which one has to proceed to locate the desired deposit

Drilling Prospecting is generally followed by drilling The drill hole can be put down vertically or at an angle, as necessary Where accurate sampling is not necessary (mainly in the case of non-metallic minerals and coal) and data are required only to find the depth and area of the deposit, a percussion drill would be suitable Where more detailed data are required, rotary drills are employed and the core-barrel brings up the actual columns of rock penetrated For rapid drilling, the cutting bits at the end of the core-barrel are armed with tungsten-carbide or diamond crystals. Drills capable of penetrating to 2000 metres or so are available for mineral prospecting For oil prospecting, the drilling technique is somewhat different, as specially prepared heavy mud (thick slurry of special clay mixed with barite or other heavy mineral) has to be used in the drill hole and large depths are involved It may be stated here that the deepest mines in the world are the gold mines of Kolar in Mysore and the Witwatersrand mine in South Africa working at a little over 3000 metres' depth, the deepest oil well on record is 25,340 ft (7722 m) on the Gulf Coast of the U S A.

After ascertaining that a deposit contains sufficient economically workable useful ore or mineral, it is opened up by a shaft or incline. Steep-dipping deposits are worked by shafts, and at several levels Mining is a complicated operation, as it involves arrangements for hand-drilling, breaking ground and ore, blasting, haulage and hoisting of material; ventilation of workings, prevention of dust production to avoid explosion and to prevent lung diseases; and the adoption of various safety practices. The arrangement of the working faces and the method of working will depend largely on the structural features of the deposit

After the ore or mineral is hauled up to the surface, it may undergo preparation for the market, which may include simple hand-picking or one or more methods of beneficiation

Mineral Beneficiation. Benefication consists of processes to improve the grade of the mineral taken out of a deposit. It may be done by utilizing the differences in density between the useful mineral and the accompanying waste material (gangue) *Shaking tables* throw up the lighter materials and concentrate the heavier ones which remain at the bottom and move comparatively slowly. In washing processes, water aids the separation In the cleaning of coal, the crushed material is agitated in water mixed with a finely powdered heavy mineral like magnetite, so that the water behaves like a *heavy liquid.* The purer, higher grade coal floats in the heavy liquid, and the impure coal and rock fragments,

which are heavier, sink to the bottom. The lighter coal can thus be separated from the heavier impure coal and rock

The *magnetic property* of minerals is used in their separation from non-magnetic materials The ore, ground down to a suitable size, is passed over a belt in a magnetic field, when magnetic minerals like magnetite, ilmenite, etc, are kept back and the non-magnetic quartz and other minerals are rejected and pushed away This process is used to concentrate ilmenite from beach sands, and magnetite from the other ingredients in a quartz-magnetite rock The electromagnetic process can be used to separate minerals of different magnetic susceptibilities (e g, magnetite, ilmenite, ferromagnesium silicates, garnet, monazite, etc) from one another and from the associated non-magnetic minerals in beach sands, or the mixed minerals in beach sands or a rock, by adjusting the strength of the magnetic field by stages

Electrostatic separation can be used similarly, because different minerals behave differently in an electrostatic field. Rutile is thus separated from some of the other minerals in beach sands

Flotation is a very useful and versatile process. The medium is a water solution of certain chemicals mixed with a suitable oil Some mineral grains are wetted by the water and others are not. When the mixed minerals in a crushed ore are agitated in such a medium, air bubbles attach themselves around the non-wettable minerals and rise to the surface and can be skimmed off while the others are wetted and sink to the bottom Some chemicals in the water act as collectors and help in the flotation while some others act as depressors. A large number of minerals, both ores and non-metallic minerals, can be treated by this process, using a variety of combinations of chemicals This process is particularly useful in treating complex ores containing several metallic minerals It has also been applied for separating minerals like barite, charbonates and phosphates

Economic mineral deposits of India

In the following paragraphs a short account is given of the more important minerals (and some mineral products) produced in India

Metalliferous Minerals

Precious Metals These comprise gold, silver, platinum, iridium and osmium. Of these, only gold and silver are produced in India. Gold occurs mainly as native gold (element), often in association with pyrite and some other sulphides in quartz veins The veins or reefs traverse the amphibole-schists of the Dharwarian system in Kolar in Mysore State, and in similar ancient schists in the Wynad area of Malabar, in Hutti (Mysore), Anantapur (Andhra), and in Singhbum (Bihar) The reefs in Kolar dip steeply near the surface, and practically vertically at depth. The average grade of ore worked in Kolar and Hutti (the only producers) is around 5 to 7 dwt per ton (1 dwt = 1 555 gm) The producing lode in Kolar is called the Champion lode which runs north-south for several miles but is worked over a length of about 5 miles. The maximum depth reached is a little over 10,000 ft As the gold is in the metallic form, the powdered ore, mixed with water, is passed over closely woven mats or blankets in which the gold particles settle down. The very fine particles passing into the slime are treated with Na CN (Cyanide) solution which dissolves the gold and from which it is separately precipitated There are still large quantities of lower grade ores in some of the lodes in Kolar

The Kolar gold field had produced £150 million worth of gold up to 1960 The annual production of gold in India is nowadays around 4300 kg, the bulk of it being from Kolar. It has been going down steadily during the last half a century, from over 10,000 kg to the present output

Silver. There are at present practically no mines in the world which produce silver as the major product. Silver accompanies gold and

lead in many ores, so that the bulk of the world's production comes from gold, copper and lead-zinc mines. In India, there is a small production from Kolar (about 10 to 20 parts silver to 1000 parts gold), and from the lead ore of Zawar, Rajasthan, which is smelted in Bihar, the total annual output being around 4000 kg

India has no deposits which produce other precious metals

Ferrous Metals

These are usually taken as including iron, manganese, chromium, nickel, cobalt, molybdenum, titanium and tungsten

Iron The chief ores of iron are hematite (Fe_2O_3), magnetite (Fe_3O_4), siderite ($FeCO_3$), and limonite and goethite (hydroxides of iron) There are three types of deposits in India The first is the banded hematite-quartzites, which form beds in the iron ores series occurring in several states, particularly Bihar, Orissa, Madhya Pradesh, Maharashtra, Goa, Mysore, Madras and Andhra These banded ores are marine sedimentary beds which have been enriched to bodies of high grade hematite through the agency of ground-water, after uplift, at or near the surface These are the sources of all our iron ore supply at present. The best ores contain over 60 per cent iron with low silica, sulphur and phosphorus, but there are also large quantities of lower grade ore

Where these ores have been metamorphosed, they have become banded quartz-magnetite ores The iron percentage in these is around 45 to 50, but they can be crushed and easily concentrated by the electromagnet to richer grades of 60 per cent and over Such ores occur in large deposits in Guntur (Andhra), Salem-Trichinopoly (Madras), and in Mysore It is proposed to utilize the Madras deposits shortly in a smelter to be set up in the Salem district.

The second type of deposits are the titaniferous magnetite bodies occurring in Eastern Singhbhum (Bihar), Mayurbhanj (Orissa) and Southern Mysore These bodies are of igneous origin and contain up to 15 per cent of $Ti O_2$. These are difficult to smelt and are not likely to be used for some years to come

The third type comprises beds of carbonate ore in the ironstone shales (Gondwana) of the Raniganj coalfield in Bengal These ores have been converted to limonite at the surface They were used by the Bengal Iron Company (which is now known as the Indian Iron and Steel Company) up to about 1918, when the rich hematite ores of Singhbhum replaced them

There are, in addition, numerous scattered deposits of laterite in many parts of India, which may receive attention in the future. Laterite is a mixture of the hydroxides of iron and aluminium (sometimes with some manganese and titanium also), containing about 30 per cent of iron Large masses of laterite occur as cappings over the Deccan Traps of Madhya Pradesh and Maharashtra and the gneisses and Tertiary sandstones of Kerala

Manganese The chief ore minerals of manganese ore pyrolusite (MnO_2), polianite (MnO_2), psilomelane and cryptomelane (hydrous Mn manganate), hollandite (manganate of Mn, Fe, Ba), braunite ($3Mn_2O_3$) $MnSiO_3$, rhodochrosite ($MnCO_3$) and a few others. The ores are usually a mixture of two or three minerals Though the best commercial ores may contain up to 54 per cent Mn, they are classed as first grade (over 48 per cent), second grade (45 to 48 per cent), and third grade (40 to 45 per cent) The deposits in India are all originally of sedimentary origin, laid down as sedimentary beds in the Precambrian rocks By metamorphism they have been altered to a rock called *gondite*, consisting of quartz, the manganese garnet spessartite and some Mn silicates. The purer sediments became mainly pyrolusite, psilomelane and hollandite Braunite is also common in Indian ores The gondite type of rock and associated ores are common in the Chhindwara-Nagpur-Bhandara area of Madhya Pradesh and Maharashtra, and in the Narukot-Jhabua area of Gujarat

In the Ganjam-Srikakulam-Visakhapatnam

area of the Eastern Ghats, the manganiferous sediments have been metamorphosed and intruded into by apatite-rich granite, the resulting rock being called *kodurite* (quartz, feldspar, manganiferous garnet and apatite) Another type of ore which is found in several places in Orissa, and in Dharwar and Kanara in Mysore, has been formed by the concentration of the manganese in some of the strata by solution and redeposition, mainly as pyrolusite and psilomelane This type sometimes contains very high grade powdery pyrolusite, suitable for use in dry batteries

The deposits of the Nagpur belt run for a distance of 200 km and contain three or four horizons of large ore bodies They contain the largest and best deposits of India and are thought to hold reserves of 80 million tons within a depth of 150 m The other deposits, in Gujarat, the Eastern Ghats and Mysore, may contain about 50 million tons.

Manganese ore is added to the furnace charge in making iron and steel Good pig iron and ordinary steel may contain 3 to 4 per cent of manganese. Special manganese steel which has great hardness and abrasion resistance (as in certain wearing parts of crushers) may contain up to 15 per cent manganese

India, Brazil, the Soviet Union, South Africa and Ghana are important producers of manganese ore The production in India has varied between 0 2 and 1 8 million tons per year India has so far produced about 48 million tons (between 1892 and 1964), most of which was exported Indian consumption is rising in proportion to the increase in the production of steel

Chromium The mineral chromite (FeO Cr$_2$O$_3$) is the chief ore of chromium First grade ore contains over 48 per cent of Cr$_2$O$_3$. It usually contains oxides of iron, magnesium and aluminium as impurities each of which may amount to 18 or 20 per cent Chromite occurs as lenses, veins and disseminations in ultrabasic rocks Good deposits occur in the Cuttack and Keonjhar districts (Orissa),

Krishna district (Andhra), Ratnagiri (Maharashtra), Southern Mysore, Manipur, Kumaon and Kashmir Indian production has fluctuated between 20,000 and 50,000 tons per year The reserves are not known, but they may be of the order of 5 million tons

The most important chromite-producing countries are Turkey, South Africa, Southern Rhodesia, Philippines and the Soviet Union Chromite is used for the refractory lining of furnaces, for the manufacture of chemicals, and as an alloying element in steel in different proportions. The best known chrome steel is stainless steel containing about 18 per cent chromium and 9 per cent nickel

Titanium. Ilmenite (FeO TiO$_2$) and rutile (TiO$_2$) are the common ores of titanium. A small deposit of ilmenite was known in Rajasthan but it has been worked out. The only source of these two minerals are the beach sands of Travancore, from which about 200,000 tons of ilmenite and 400 to 500 tons of rutile have been produced per year. The present production of ilmenite is much less. Other beach deposits occur in Orissa, southern Madras and Maharashtra

Both the minerals, and especially ilmenite, are used as sources of titanium metal and for making steel During the last 20 years, metallic titanium has been manufactured and used in machinery and some structural parts which have to work under conditions calling for resistance to high corrosion, e g , corrosion from certain chemicals and sea water Rutile is used in welding rods to give high quality welds in steel

Ilmenite is used extensively for making the paint pigment known as *titanium white,* which is really TiO$_2$ but is bright white It can be used by itself and in mixture with other paints

Large deposits of ilmenite, occurring as lenses, are worked in New York State. Beach sands are worked in Brazil, West Africa, Malaya and Australia

Tungsten The best known tungsten minerals are wolframite (Fe,Mn)WO$_4$ and scheelite

(CaWO₄) Only three or four small deposits of wolfram are known in India—near Degana (Rajasthan), near Nagpur, Tatanagar, and in West Bengal. The latter were worked during World War II for a short time Degana produces a few score tons from time to time

Tungsten is used in carbon steel for making hacksaw blades and superior tools Special machine tools, which keep their cutting edges without softening almost up to red heat (550° or 600°C), are made of high-speed steel, which may contain 12 to 20 per cent W, 2 to 5 per cent Cr and 0 5 to 2 2 per cent V In some of these steels, Mo is partly substituted for tungsten The largest sources of wolfram are Burma, Malaya, South China and U S A

Nickel and Cobalt Minerals of these metals are rare in India Cobaltite (a sulpharsenide) and another cobalt mineral are found in small quantities in the Khetri copper deposits They have been used in a small way for making a blue enamel for the jewellery trade in Rajasthan

Nickel and cobalt often occur together as sulphides, sulpharsenides, sulphantimonides, etc Nickel is used in a large variety of steels for various purposes, mainly due to the research carried out by the International Nickel Co , of Canada, where the world's largest deposits occur. Some nickel steels are non-magnetic and others (permalloy) possess high magnetic permeability (50 to 75 per cent Ni) *Invar* (with 30 to 42 per cent Ni) is an alloy with a very low coefficient of expansion, it is used in measuring scales, tapes, chromometer parts, etc *Chromel* and *nichrome* (with 65 to 85 per cent Ni, 15 to 20 per cent Cr, and the rest iron) have high electrical resistance and are used in heating elements Some nickel alloys have very high tensile strengths. *Platinite* is an alloy with 45 per cent Ni, having the same coefficient of expansion as platinum and glass, and therefore very useful in sealing wires in glass (e g , in electric lamps). Stainless steels are made in different compositions and are used extensively in the dairy, food and several chemical indus-

tries Canada and New Caledonia are the largest sources of nickel

Cobalt, similarly, enters into several alloy steels *Stellite* is a high-speed steel containing 45 to 70 per cent cobalt, 30 to 35 per cent chromium and 3 to 17 per cent tungsten It has also high abrasion and corrosion resistance Certain compositions (e.g., 57 per cent Fe, 35 per cent Co, 4 per cent W and 2 per cent Cr) make an excellent alloy for permanent magnets A tungsten carbide with cobalt (86 W, 10 Co, 4 C) is a very hard abrasive Northern Rhodesia and Congo are the largest sources of cobalt in the world. There are some small nickel and cobalt deposits in Nepal

Molybdenum It is obtained from a sulphide and an oxide. There are only a very few deposits in the world, the best known being in Colorado, U S A Molybdenum steels have high strength, wear resistance, and toughness Molybdenum can be added to certain chromium, tungsten and cobalt steels to strengthen particular properties.

Vanadium It occurs with titanium in some magnetite deposits and also in association with uranium ore Vanadiferous magnetite occurs in Singhbhum (Bihar) but has not been exploited as the recovery of the element poses difficulties in metallurgical treatment Vanadium steels have great strength and wear resistance, and are used for heavy forgings, locomotive parts and frames, and in boiler tubes, etc

Vanadium ores occur with uranium ores in the Colorado plateau in the U S A. Large deposits of patronite (VS₄) occur in Peru in South America.

Common Metals

Copper The most familiar metal in this group is copper Native copper occurs in lava flows, but occasional, small quantities occur in the Deccan Traps of India. Large masses of native copper have been worked from the lavas of Michigan, U.S.A.

The main sources of copper in the world are vein and lode deposits in the form of sulphides and other compounds The following are some

of the important compounds: Chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS), bornite (Cu_5FeS_4), tetrahedrite [$Cu,Fe)_{12}Sb_4S_{13}$], tennantite ($3 Cu_2S. As_2 S_3$), cuprite (Cu_2O), tenorite (CuO), malachite—$CuCO_3 Cu(OH)_2$, azurite ($2 CuCO_3.Cu(OH)_2$), chalcanthite ($CuSO_4 5 H_2O$), atacamite ($CuCl_2 3 Cu (OH)_2$). The sulphides and sulpharsenide-sulphantimonides are the primary ores and they are often converted to oxides, sulphates and carbonates near the surface Malachite and azurite are conspicuous in the outcrops because of their arresting green and blue colours

Copper ores are often associated with ores of other metals like Ni, Co, Pb, Zn, etc. A number of these ores are becoming valuable by-products of copper mining

Several countries are good copper producers, the more important ones being the USA, Canada, Chile, N Rhodesia, Congo, Japan, USSR., Spain, etc India has only one producing mine in Singhbhum (Bihar), located in a zone of overthrust in the Precambrian rocks, associated with uranium ore The annual production of copper from this mine, which is smelted near the mine, is about 9000 tons per year.

There are a few other copper deposits in India, which are under investigation and development. The deposits at Khetri in Jaipur are said to contain large reserves of low grade ore Three or four deposits near the eastern border of the Cuddapah basin in Andhra and one in South Arcot in Madras are under investigation These are likely to be good deposits. A few deposits are also known in Sikkim.

Next to iron, copper is the most useful metal. Brass and bronze are the best known alloys of copper Springs with a very high fatigue resistance are made from an alloy of copper and beryllium Copper is also used extensively in the electrical, munitions and building industries.

Lead and Zinc The ores of these two metals occur together The chief minerals are sphalerite ($Zn S$) and galena (PbS), which are altered near the surface to cerussite ($PbCO_3$), anglesite ($PbSO_4$), smithsonite ($Zn CO_3$), and calamine ($H_2 Zn Si O_5$) The only deposits now worked in India are those of Zawar near Udaipur (Rajasthan). The ore occurs as replacements of the dolomites of the Aravalli system, which dip steeply The present production is around 700 to 800 tons of ore per day, containing 4 to 7 per cent of the two metals together The ore becomes richer in zinc at depth. Only the lead concentrates are smelted in India, the zinc concentrates are exported There are four deposits in the area which may have reserves of the order of 10 to 15 million tons. The present production is about 2500 tons of lead (and a little silver) and 1200 tons of Zn concentrates.

Some other deposits occur in Jaipur (Rajasthan) and in Andhra Pradesh, but they are yet to be fully investigated.

Other Metals

Aluminium. The chief aluminium ore is bauxite, which is a hydroxide of aluminium It is a product of the weathering of high-alumina shales and clays and highly feldspathic rocks Deposits are found as residual caps, the chief ores in India being in Bihar, Madhya Pradesh, Gujarat, Maharashtra and Madras. The amount of bauxite of all grades has been estimated at 250 million tons, of which less than 50 million tons is of high grade. There are at present three aluminium smelters in India and their combined production is around 30,000 tons, this production is, however, rising

Magnesium. Though magnesium occurs in many minerals, particularly silicates, only magnesite ($Mg CO_3$) was at one time used as a source for the metal Nowadays, magnesium is recovered from sea water, so that the magnesium-bearing minerals are utilized for other purposes.

Calcined and 'dead burnt' magnesite are used for lining furnaces which require a basic refractory; for this purpose an iron content of some 6 to 8 per cent in the magnesite is desirable In the past, the mineral was also used for making oxy-chloride cement for flooring

India has large deposits of magnesite in the Salem district of Madras and in Southern Mysore where it has been derived from the hydrothermal alteration of dunite (ultra-basic olivine rock) These deposits contain over 80 million tons within a depth of 30 metres A few million tons are also present in the dolomite bands of the Precambrian Age at Dechawri and at other places in the Almora District (U.P.).

Tin In India, two or three small occurrences in granitic rocks of tin ore (cassiterite, SnO_2) are known in the Hazaribagh and Ranchi districts of Bihar, but they are not profitable to work The chief sources of tin in the world are the following granite belts. Shan-Thailand-Malaya-Indonesia and Southern China in Asia, Nigeria in W. Africa and Bolivia in South America.

Uranium and Thorium. Though a very large number of uranium-bearing minerals are known, the chief ones are uraninite or pitchblende (uranium oxide) and its alteration products—torbernite (copper uranate) and carnotite (potassium-uranium vanadate). The chief source in India lies in the copper belt of Singhbhum, where torbernite and other U-minerals occur in association with copper ores. These deposits are estimated to contain 10 to 12 million tons of ore with 0 05 to 0.1 per cent U_3O_8 The mica-pegmatites of Bhilwara and Ajmer in Rajasthan, Gaya and Hazaribagh in Bihar, and Nellore in Andhra contain some sporadic uranium minerals which are not of economic value

Before atomic energy was developed, uranium minerals were used for making paints and as an ingredient of glass The chief deposits in the world are in the Congo, the Great Bear Lake area in North-west Canada, the Colorado plateau in the U S A , South Australia, Czecho-slovakia, and some other places

The chief thorium minerals are: monazite (a cerium phosphate with Th), thorianite ($ThSiO_4$) and thorite (Th-V oxide) They are found mainly in the heavy mineral beach sands of Brazil, West Africa, Ceylon, Malaya, Australia, etc

In India, the beach sands of Travancore, Madras and Orissa, and the soil in some parts of Ranchi (Bihar) contain several million tons of monazite, with about 6 to 8 per cent Th O_2 Thorium nitrate has been used in the manufacture of gas mantles (for emitting bright light), while Th O_2 is a super-refractory Thorium is an atomic energy element.

Zirconium Zircon (Zr SiO_4) is the chief zirconium mineral It is a minor constituent of the heavy mineral beach sands of Travancore and Madras Zr has been used as an alloying element in steel, while the oxide is used as a super-refractory

Non-metallic or industrial minerals

Abrasives Modern industry uses a variety of minerals for grinding and polishing Diamond and corundum are costly, but garnet, quartz and some other siliceous materials, and magnetite and several artificial products are used as cheap abrasives The polishing materials include diatomite (mainly silica), kaolin, limestone, chalk, steatite and red oxide (hematite)

Asbestos Of the four major types of asbestos in use in the world, India has some resources of the chrysotile (serpentine) and amphibole types. Chrysotile of good quality occurs in the Cuddapah District (Andhra) in the dolomites of the Cuddapah Age along the zone of contact with a sill of basic igneous rock The annual production is around 400 to 500 tons. Amphibole asbestos occurs in several places Singhbhum and Dhanbad in Bihar; Mayurbhanj in Orissa; Alwar, Udaipur and Idar in Rajasthan, Bhandara in Maharashtra; and southern Mysore. These sources produce about 1200 to 1500 tons per year

Barite. (Ba SO_4) occurs as veins at several places in the Cuddapah basin of Andhra and in the Alwar district of Rajasthan The reserves are considerable, though the exact amount is not known. The annual output is around 20,000 tons, which is consumed by the paint industry and in oil well drilling

Clays A large variety of clays of different

grades occur extensively in India Kaolin (China clay) is worked in the Rajmahal area and in the granite belt of Bihar and Kerala Refractory clays are worked in the coal-fields of Bengal and Bihar, and also in Mysore and Madras The shales in the Cuddapah basin and at other places have yet to be tested systematically. Brick and tile clays are extensively worked from river deposits in the several river valleys and deltas, and from many areas with thick soil cover Bentonite and bleaching clays are exploited in several areas in Rajasthan, Gujarat, Mysore and Bihar. Some 20,000 tons of bleaching clays and perhaps nearly a million tons of other clays are produced annually in India

Gemstones Though celebrated as a producer of diamonds for many centuries, India produces at present only a few hundred carats of gems and industrial diamonds, mainly from Panna in Bundelkhand Wajra Karur in Anantapur district (Andhra) occasionally yields a few stones Small quantities of sapphire are got from Kashmir, and of aquamarine from the pegmatite deposits of Rajasthan, Bihar and Nellore. A few thousand carats of emerald are got from Udaipur and Ajmer in Rajasthan Garnet is got from several areas but there is no regular production The Deccan Trap yields large quantities of clear quartz and several varieties of chalcedony (agate, carnelian, jasper, chrysoprase, moss-agate, etc.), the centres of trade being mainly in Gujarat Other gemstones are rare or absent.

Graphite. Graphite of good quality for making crucibles is worked in several areas in the Eastern Ghats, in Bolangir-Patna in Orissa, in the Visakhapatnam-Godavari districts of Andhra, and in Travancore. Smaller deposits and graphitic schists occur elsewhere also. About 300 tons are produced in the country each year.

Gypsum Deposits of gypsum occur in the Vindhyan Strata in Jodhpur and neighbouring areas, in the sub-recent sands of Bikaner, in the cretaceous strata in Trichinopoly (Madras), and in recent marine silts in Kutch, Kathiawar and Andhra There are also some good deposits in Kashmir and Garhwal The annual production is about 1 million tons, most of which is used for the manufacture of ammonium sulphate fertilizer at Sindri Some quantity is also used for grinding with Portland cement, to which it is added to the extent of about 4 per cent The total reserves are of the order of 750 million tons.

Limestone and Dolomite These are used as flux in smelting iron Limestone is used for making cement and lime, large quantities are also employed as building stones

Limestone and dolomite occur in all the States of India and in most of the geological formations. The total reserves are very large, running into several thousand million tons The recorded output of limestone is about 18 million tons and of dolomite over 1 million tons, but probably much more is actually used as there are no strictly reliable records of the amounts quarried locally in villages

Mica. Both muscovite and phlogopite are exploited in India. The bulk of the muscovite deposits are in the mica belts of Rajasthan, Bihar and Andhra, but several deposits also occur outside these areas Phlogopite (or semi-phlogopite) occurs in Orissa and Kerala. The annual production of muscovite is of the order of 25,000 tons in the crude form, including 'scrap' which is also exported India is one of the most important producers of block mica in the world.

Pyrite India has no useful deposits of natural sulphur Present-day marine silts on the coast near Masulipatam (Andhra) contain small quantities of sulphur, produced by bacterial action on sea water. This occurrence is only of theoretical interest

Pyrite occurs as sporadic veins in the Pre-cambrian gneisses and schists A good deposit, containing over 1 million tons of pyrite, occurs near Chitaldrug in Mysore state Another good deposit occurs as a sedimentary bed in the Lower Vindhya formations near Dehri-on-Sone in Bihar The outcrops of the bed are seen in the

16

scarps of the hills at a few places and the bed apparently extends over an area of several tens of square kilometres. Drilling in the area is said to have proved the existence of a few million tons of pyrite containing 40 to 45 per cent sulphur The deposits are being opened up.

There is also the possibility of recovering the sulphur in the gases of the copper smelter in Singhbhum, and from the projected zinc smelter which will use the Rajasthan zinc ores

Phosphates. Lenses of apatite-magnetite rock occur in the Singhbhum copper belt They occur in a series of masses over a distance of some 60 km, the individual masses being up to 300 m long and 20 m thick. The material can be concentrated by the electromagnetic separator, after crushing it to proper size. This belt probably contains about 0 75 million tons within a depth of 30 m

Small lenses of apatite occur in the gneisses and khondalites of the Eastern Ghats near Vizianagram (Andhra) The reserves are only a few thousand tons

Nodules of a mixture of fine-grained calcium phosphate, calcium carbonate and clay occur in an area of several square kilometres in the Uttattur strata (cretaceous) in the Trichinopoly district of Madras. Owing to the fine-grained nature of the ingredients, the phosphate is difficult to separate economically The reserves of the phosphatic nodules in the area are of the order of 3.5 million tons, if they continue to occur down to a depth of 30 m

Sillimanite and Kyanite These two minerals are aluminium silicates (Al_2O_3 SiO_2) and are used as high grade refractories in glass furnaces and for heat insulation to at least 1600°C Very good deposits of massive sillimanite, sometimes in association with corundum or with quartz, occur in the Khasi hills on the Assam plateau. Some other deposits occur in Rewa. The total reserves of sillimanite in both these are of the order of 0 35 million tons within a depth of 10 m, there is a possibility of downward extension.

Excellent kyanite deposits occur in Singh-

bhum, parallel to the copper belt, in the schistose rocks These are estimated to contain 1 million tons within a depth of 6 m, and are likely to extend further down. Some smaller deposits occur in the Nellore district (Andhra) and Hassan district (Mysore) The present annual production is 15,000 tons of sillimanite and 20,000 tons of kyanite

Salt The only rock salt deposits in India occur in the Eocene strata in Himachal Pradesh They are worked by underground methods and the annual production is only 3000 tons Salt is recovered from the Sambhar lake in Rajasthan to the extent of half a million tons per year.

Salt is also made by the evaporation of sea water in salt pans along the coast in many areas, the total production being a little over 4 million tons This shows that the per capita consumption of salt in India is only about 10 kg as against 50 kg in the western countries, this gives a measure of the comparative industrial advancement.

Steatite. Steatite, or talc, occurs in nearly pure masses and also as a schistose material with impurities. The latter is used for making cooking pots, bowls, statuettes and other objects The pure massive material is used as an insulator of heat and electricity in the electrical and radio industries Good quality steatite is finely ground and used in talcum powder and in other cosmetics, as an adulterant in soap, and for other purposes

Good deposits occur in Jaipur and Udaipur in Rajasthan, near Jabalpur in Madhya Pradesh; and in Mysore, Andhra and Madras. The annual output is of the order of 20,000 to 25,000 tons An appreciable quantity of talc-schist is quarried and used in the villages for local purposes

Some organic substances are also commonly included under the term 'minerals' These are coal, petroleum and natural gas—all compounds of C, H, N and O, usually referred to as hydrocarbons They are used as fuels for heating and for generation of power, and as raw materials for some chemical industries

Coal

Coal is a natural hydrocarbon occurring amidst sedimentary rocks as beds which generally have uniform thickness unless they are folded or disturbed The beds may be horizontal or inclined They vary in thickness from mere streaks to seams over 30 metres thick, e g , the Bokaro coal-field in Bihar and Singrauli in Madhya Pradesh.

Coal has been formed from the accumulation vegetation in former ages, such as the Carboniferous, Permian and Tertiary The vegetation accumulated to great thickness in swamps and lakes by the slow sinking of the bottom, which kept pace with the accumulation, followed by a slow lifting up

The vegetable material was transformed, under anaerobic conditions, by chemical changes aided by bacterial action, it changed progressively to peat, lignite and coal The pressure of the layers on top helped to increase the carbon content and decrease the volatile and moisture content of the coaly material. Anthracite has been formed only in areas where the strata have suffered much pressure through earth movements

Coal seams show varying degrees of purity, as they are contaminated by clay and sand deposited at the same time They may change in composition when followed along the strike or dip directions Under the microscope, coal may show various constituents of the original vegetation, like woody tissue, bark, spores (seeds) and also colloids of complex hydrocarbons.

Composition of Coal Coal is analysed to show either the 'proximate' or the 'ultimate' composition The proximate analysis shows the moisture, volatile matter, fixed carbon and ash (mineral matter in the coal) and, sometimes, sulphur and phosphorus The calorific value is the amount of heat (calories) evolved during the combustion of 1 kg of coal The ultimate analysis shows the composition of coal in terms of carbon, hydrogen, oxygen and nitrogen. For comparing the analyses, the values are given on an ash-free and moisture-free basis.

TABLE 4 3

AVERAGE 'PROXIMATE' ANALYSIS OF COALS

	Moisture	Volatiles (per cent)	Fixed C	Ash
Lignite	34 55	35 34	22 91	7 20
Sub-bituminous	24 28	27 63	44 84	3 25
Bituminous	3 24	27 13	62 52	7 11
Semi-anthracite	3 38	8 47	76 65	11 50
Anthracite	2 80	1 16	88 21	7 83

TABLE 4.4

AVERAGE 'ULTIMATE' ANALYSIS OF SOLID FUELS

	C	H	N (per cent)	O	Calories per kg
Wood	49 65	6 23	0 92	43.20	—
Peat	55.44	6 28	1 72	36.56	—
Lignite	72 95	5 24	1 31	20 50	4600-6000
Bituminous	84 24	5.55	1 52	8 69	7700-8600
Semi-anthracite	91 47	4 25	1.64	2 64	8300-8800
Anthracite	93 50	2.81	0 97	2.72	8000-8500

Coal-beds occur in many parts of the world, the major producers being the U S A., U.S S R , U.K , Germany, France, Poland, China, South Africa, India, and some other countries. The world production of coal is about 1600 million tonnes per year.

In India, coal is found in beds of two different geological ages. The most important seams occur in the lower Gondwana Strata of the Permian Age The other group, which contains much lignite, is of Tertiary age Gondwana coal occurs along three major faulted basins in north-eastern India: along the Damodar and Sone Valleys in Bengal, Bihar and Madhya Pradesh, along the Mahanadi valley; and along

the Godavari Valley The Tertiary coal-seams are found on the Assam Plateau and in upper Assam; along the foothills of the eastern Himalayas and in the Jammu province of Kashmir, in the Bikaner district of Rajasthan, in Kutch and parts of Gujarat; and in the coastal belt of Madras and Kerala

India's total resources in coal are approximately 80,000 million tonnes of Gondwana coal and 10,000 million tonnes of Tertiary coal The present production is about 65 to 70 million tonnes per year, most of it is Gondwana coal

Petroleum

Petroleum is a complex mixture of liquid hydrocarbons belonging to several hydrocarbon series The paraffin, haphthene and benzene series make up the bulk of these Some sulphur compounds are always present

Origin of Petroleum. Both inorganic and organic sources have been suggested for the origin of petroleum Berthelot, in 1866, suggested that hydrocarbons may be formed by the action of water on the calcium carbide inside the crust Mendeleeff, in 1877, suggested that they may result from the action of hot water or dilute acid on carbides of iron and manganese, Though this theory had great support till the beginning of the present century, and its supporters included several great French chemists, it is now abandoned.

Research conducted during the last three decades by many petroleum chemists and geologists has indicated that marine sediments are the most likely source of petroleum The organic matter is broken down and built into various hydrocarbons with the aid of bacteria Certain compounds in petroleum, especially those with intermediate boiling points (250° to 300°C), possess the power of rotating the plane of polarization of light. This characteristic, which is seen in several organic substances but only in two minerals (quartz and cinnabar), gives support to the theory of the organic origin of petroleum.

Petroleum generally migrates from its mother rock into a suitable reservoir rock like porous sandstone or limestone Being lighter than water it accumulates above the layer of water in the strata and is accompanied by gas Much gas is also dissolved in the petroleum as it is under great pressure at depth

Oil pools are found in strata folded into anticlines and domes and in other suitable locations (traps) like sealed faults and at the junction of strata where porous rocks thin out between non-porous rocks Oil reservoirs have non-porous clay strata above and below, to keep the petroleum from dissipation

Prospecting for Oil Oil finding is a specialized job requiring the work of geologists and geophysicists who deduce the types of suitable structures which may exist underground Gravitational, magnetic and seismic investigations give data which are interpreted to get a clue to the structures Many structures, though they may appear suitable, do not contain petroleum because there may have been no suitable mother rock to produce the petroleum Even in the case of a structure producing petroleum, only a part of it may be productive Petroleum is obtained by drilling, which is expensive and employs very specialized techniques.

There are usually several petroliferous zones in the reservoir rocks When the bore-hole reaches the oil-bearing horizon, the petroleum may shoot up violently if there is high gas pressure. In other cases, there may be no 'gushers', and the oil has to be pumped up to the surface When the production from a well goes down, special methods are employed, like re-pressuring of the strata by gas or partial flooding, to induce the oil to come out

Petroleum (crude oil) is a thick, dark, viscous liquid. Its colour is dark green, greenish brown, or even black Its density is between 0 8 to a little less than 1 0 It generally smells of kerosene Its viscosity may vary, depending on its composition Oil which is rich in waxy or asphaltic material is more viscous than the oil containing more volatile compounds.

What is meant by the 'cracking' of petroleum?

As petroleum is a complex mixture, it is broken up into various fractions by distillation at different temperatures It is also treated by a process called 'cracking', in which a catalyzer is used and the larger molecules are cracked or broken up into smaller and simpler molecules The various fractions obtained from crude oil are · gas, aviation and ordinary petrol, benzol, kerosene, diesel oil, lubricating oil, paraffin wax, and asphalt Different oils contain different proportions of these fractions The proportions can be slightly altered during distillation or cracking.

The heavy final fraction (asphaltic) is the raw material for the petrochemical industries Many kinds of chemicals are made from it by various specialized process The substances produced include dyes, perfumes antiseptics, explosives, drugs and other chemicals.

As early as the seventeenth century, petroleum was raised from hand-dug wells in a few places (e g, U S S R and Rumania) and used for medicinal purposes. Asphalt was used for making ships leak-proof and waterproof Ordinary hand-dug wells have been operated in Burma even up to 1930 The first oil well was drilled in Pennsylvania (U S A) in 1858, it is known as the Drake well By the beginning of the present century, petroleum had become a big industry.

Geology and geophysics have been prominently used in oil finding, especially after World War I.

Many countries now produce petroleum and vast sums are spent for discovering new sources The chief producers are the U S A, the U S S R, Venzuela, Kuwait, Saudi Arabia, Iran, Iraq, Algeria, Libya, Indonesia, Rumania, Mexico, Argentina, Columbia, Egypt, Trinidad, and several other countries The total world production is over 1300 million tonnes per year India's production is only 2 million tonnes, but it is gradually rising The world reserves of petroleum are around 45,000 million tons, of which more than half are in the Middle East, and of the remainder, the major part are in the U S S R, U S A, and the Caribbean region.

Useful Materials

I. Metals and alloys

Our present civilization is largely based upon the use of a few metals. We make wide use of metals such as iron, aluminium, copper, zinc and tungsten in our daily life, these are used in homes and in factories and for industrial and civic purposes. All these metals are extracted from the minerals found in various rocks in the lithosphere There is a constant demand for various metals in tool making, engineering, transport, production of atomic energy, etc. Metals can be combined with each other to form alloys Alloys are, in many cases, superior to the pure metals or are more useful for specific uses. For example, we can combine strength with lightness in aluminium alloys, or can obtain material which can resist corrosion and withstand high temperatures by using tungsten alloys.

Metals have played an important role in the lives of the people since ancient times. Copper was the first metal to be used by man, since it was easily obtained Later on, people noticed that the hardness of copper increased greatly when a small amount of tin was added to it The material, which was made by adding tin to copper, came to be known as bronze. The age of bronze can be traced back by about 5000 years. Free copper was known to ancient India. The people of Mohenjodaro and other contemporary towns knew about the uses of copper as well as bronze

About 3500 years ago the Hittites of West Asia started to use iron They succeeded in forging weapons from iron. These weapons were superior to those made from bronze Iron weapons were largely responsible for the victory of the Hittites over the Egyptian Empire in 1400 B C

A number of metals were known to the ancient Egyptians, Indians, Greeks and Romans Among these were gold, silver, mercury, copper and tin. Subsequently, iron and lead were also widely known Since these metals, except for gold, occurred usually in the form of ore, the skill required to extract metals and to convert them into a useful form was a specialized art in the ancient times Only selected craftsmen knew it well. They devoted all their time to metal working, and carefully guarded the secrets of their art These craftsmen, who today would be called metallurgists, were the chosen specialists of ancient civilizations

Later, perhaps about 1500 years ago, metal working drew the interest of a class of people who were known as alchemists Their ambition was to change ordinary metals (called by them base metals) into gold. These people speculated on the relationships between metals and the heavenly bodies They did not succeed in their aim of making gold Yet their many experiments led to the discovery of several other metals, such as zinc, arsenic, antimony and bismuth. They developed laboratory techniques such as distillation and, in a way, contributed

a great deal to the later science of metallurgy It was only in the eighteenth century that modern metallurgy began, helped by the advances in chemistry Metallurgy could be understood in terms of chemical reactions. The different stages in the formation of metals, such as reduction and purification, were put on scientific lines as their chemistry became clear Great progress was made in metallurgy during the last part of the nineteenth century and the beginning of the twentieth century The structures of metals were examined by microscopes and X-rays. Metals were treated and alloyed to get useful physical and chemical properties In this development, physicists, chemists, metallurgists and engineers have all played important roles.

Metal working was known as an art in ancient India. The best example of this art can be found in the great iron pillars made during the reign of Asoka, these are examples of fine workmanship These pillars have not been affected by atmospheric corrosion even after two thousand years of weathering The tradition of metal working continues in our country, in the brass work of Varanasi and in the silver and gold wire work, known as filigree work, of Orissa and Rajasthan

Nearly 60 of the 90 elements occurring in nature are metals The rest are either nonmetals or have properties intermediate between those of metals and non-metals Elements which do not possess the properties of metals are called non-metals But this division of metals and non-metals is not very sharp There is no one property of metals which is not shared by any non-metal. On the other hand, many metals have some of the properties of non-metals The naming of a particular material as a metal or non-metal has some historical background If we want to understand metals, we must scrutinize their properties more carefully. We must understand the crystalline and atomic structures of metals. All metals, except mercury, are solid at normal temperatures Their atoms are arranged in an orderly manner.

Roughly, we can imagine the atoms as spheres which are closely packed in the solid metal This closely packed arrangement has been described in the chapter on Matter and Energy.

The atoms of an element are made up positively and negatively charged particles The positively charged particles form the central core of an atom, while the negatively charged particles are electrons moving around the nucleus. In metals, some electrons in the atoms are easily detached. These detached electrons move about freely in the metal This means that they do not belong precisely to any particular atom and can move easily from one atom to another This property of electron delocalization is responsible for many of the typical properties of metals, such as their ability to conduct electricity easily

Metals generally melt and boil at higher temperatures, as compared to non-metals They usually possess a lustre and are good conductors of heat and electricity. Another interesting property of metals is known as plastic deformity When we apply force to a metal, it can be deformed permanently to a greater or lesser degree. Thus, metals can be obtained in desired shapes by using high pressures If we apply a potential difference between two points of a metal, an electric current flows between these two points The delocalized electrons can move easily under the force of electric potential This movement of electrons is the flow of electric current. Generally, metals which are good conductors of electricity are also good conductors of heat. This is so because the electrons that carry current easily by virtue of their mobility, also carry the energy of their motion from one part of a metal to another as easily.

Although about sixty metals are known, only a few of them are commonly used. Iron is still the most useful metal. But some other metals are also coming into common use in our daily life, amongst these aluminium may be especially mentioned Copper, lead, tin, zinc, magnesium, nickel, chromium, tungsten and titanium are some of the other metals now in common

use New uses of metals are being discovered daily. The requirements of modern technology are increasing very fast and man is trying to find metals, and their combinations (alloys), with specific properties Progress in modern technology depends heavily on the skill of the metallurgist The metallurgist has to provide 'tailor made' metals required for rockets, aeroplanes, automobiles, satellites, and other products.

Metallurgy

Very few metals are found free in nature Only small quantities of gold, silver, platinum and, possibly, copper have been found in the free state All the other metals, including copper and silver, occur in the combined form Most metals are found in combination with oxygen or sulphur, and are known as ores when they occur in the earth's crust. Ores are also discussed in the chapter on Minerals

The process of getting pure metal from the ore is often complicated For every metal, there has to be a special method of treatment which is known as its extraction and metallurgy. Metallurgy is even now partly a science and partly an art There are no set rules applicable in the case of all metals The techniques are developed by trial and error Some ores produce metal easily while others have to pass through a number of complicated stages before the pure metal can be obtained Ores are rarely found pure in nature Very often, they are mixed with sand, gravel, clay, limestone and other stones When these earthy materials are present in large amounts, the ore cannot be used directly for metallurgy. It has first to be concentrated There is no set process for concentration of ores Many chemical and physical methods are used for the purposes of concentration. A widely used method is the 'flotation process'. In this process, ore is first crushed and then agitated in water containing some frothing agent such as oil or soap Due to agitation, the metal-containing particles rise with the froth, while the earthy matter sinks to the bottom. The froth is skimmed off and dried, giving purified ores. The

oxide ores are reduced with the help of a reducing agent such as carbon or hydrogen The process can be a simple one-step reduction to metal, or it can involve a number of steps. On the other hand, sulphide ores are generally first converted into metal oxides This process is called 'roasting' The metal oxide produced by roasting is then reduced to metal by some reducing agent The sulphur dioxide produced by roasting the sulphide ores is a useful by-product and is used to produce sulphuric acid or fertilizers, or both. Sulphuric acid is needed in many industries The metallurgist has to understand the chemical reaction very well if he wishes to obtain a high yield of metal We know that all reactions are reversible, this means that they can take place in both directions For any reaction, there is always a chemical equilibrium under a certain set of conditions Let us consider the case of the combination of a metal with oxygen :

$$M \text{ (metal)} + nO \rightleftharpoons MO_n$$
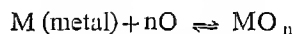
This reaction has been shown as taking place in both directions The two arrows indicate that there is equilibrium between the reaction taking place in one direction and the reaction taking place in the opposite direction Thus, at equilibrium there will be a definite ratio between the quantities of metal, oxygen and oxide A good understanding of this equilibrium enables the metallurgist to create conditions in which the reaction from right to left becomes more important, which means that the oxide breaks up into metal These conditions depend upon the attraction of the metal for oxygen or sulphur, the tendency of the oxide to decompose and the choice of an agent which may have greater attraction for oxygen than that of the metal. Many useful calculations in this direction have been made by chemical engineers, physical chemists and metallurgists.

Iron Iron ore generally consists of iron oxide, Fe_2O_3 and Fe_3O_4 In the extraction of iron, the oxide is mixed with carbon and heated to a high temperature in a furnace

$$2Fe_2O_3 + 3C = 4Fe + 3CO_2$$
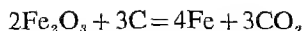
Iron oxide + carbon = iron + carbon dioxide
The carbon combines with the oxygen of the ore and thus releases the iron metal The process is known as 'reduction of the ore'. In the actual process, a mixture of ore, coke and limestone is dropped from the top while hot air is blown through nozzles in the lower part of the furnace. Due to the blowing of air, the coke attains a high temperature during burning, and molten iron is formed The iron melt is heavier than the mixture and so accumulates at the bottom The purpose of adding limestone is to remove the earthy matter present in the
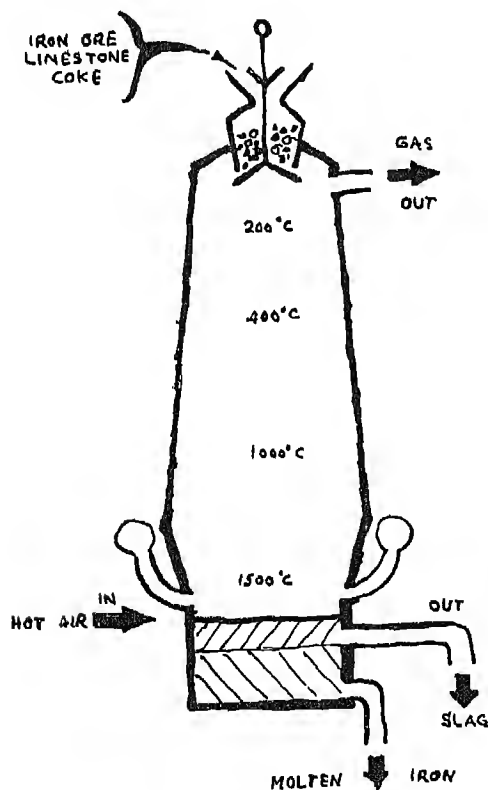

FIG 5.1. *Reduction of iron ore the blast furnace*

ore. The limestone reacts with the earthy matter at that high temperature and forms a slag The slag is light and so floats over the iron, from which it can be easily removed Although the slag is an unwanted material during the metal-

lurgical process, it has now found several uses The slag is employed in making cement, and also for making fertilizers India has extensive iron ores in many areas of Bihar, Orissa, Madhya Pradesh, Andhra Pradesh and West Bengal The steel factories are situated in Bihar, West Bengal, Madhya Pradesh and other areas.

Copper Copper is mainly found combined with sulphur. As with iron, the sulphide ore is mixed with coal and limestone and heated in the furnace under a blast of air The copper sulphide is first converted into oxide by the action of air. The oxide is then reduced to copper in the presence of coke. The metal obtained by this process is not pure However, pure copper is needed in many industries The modern process for purification of copper is based on the use of electricity In this process
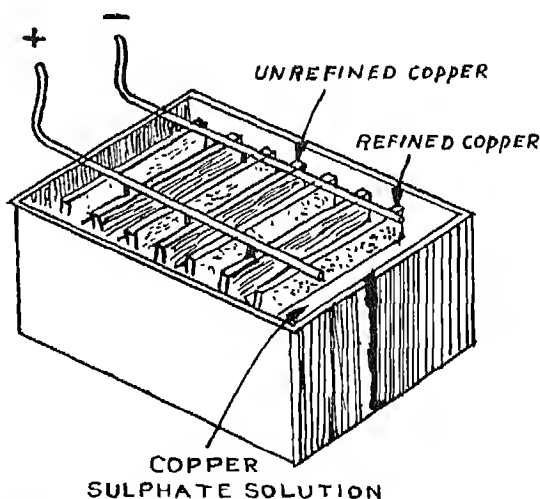
FIG. 5 2 *Electrolytic refining of copper*

two plates of copper are taken. One plate is the impure copper obtained by reduction and the other plate is pure copper. These two plates are dipped in a solution of a copper salt An electric current is passed in the solution through these two plates The plate of impure copper starts dissolving when the current is passed, and the dissolved copper re-deposits on the pure copper plate The impure

copper contains small amounts of some costly metals, such as gold. During the process of purification, these impurities settle at the bottom of the vessel, from where they are extracted These are useful by-products obtained during the metallurgy of copper

In India, copper mines are found in Ghatshila (Bihar), where copper is extracted in a plant

Copper has a number of uses With the exception of silver, it is the best conductor of electricity, and so is widely used in making electric wires Another interesting use of copper is in offset printing where it is used for making a very large number of impressions The usual type metal is soft and so wears down on printing a large number of copies of any matter In offset printing, a wax mould of the type is first made This mould is carefully dusted with a thin coating of powdered graphite, which is a conductor of electricity. The graphite-covered mould is dipped in a bath of a copper salt containing a copper electrode As the electric current passes, the copper dissolves from the plate and gets deposited on the mould Thus a copper mould of the type-matter is prepared The wax is then melted and the plate that has been prepared is supported by fillings of lead so that it does not break during the process of printing

Aluminium Aluminium oxide is the main ore of aluminium and is known as bauxite Aluminium has a great affinity with oxygen Aluminium oxide cannot be reduced by carbon, as is possible with iron and copper. Metallurgists have employed the electrolytic method for removing oxygen from aluminium oxide This method is based upon the passage of electric current through a solution or melt of aluminium salt, similar to the principle used in purifying copper. Aluminium oxide is a solid and cannot melt easily. Its melting point is above 2000°C So the method used is to make a solution of aluminium oxide cryolite (sodium aluminium fluoride) Cryolite is a convenient salt of aluminium since it is obtained in nature as a mineral, which melts at about 1000°C and
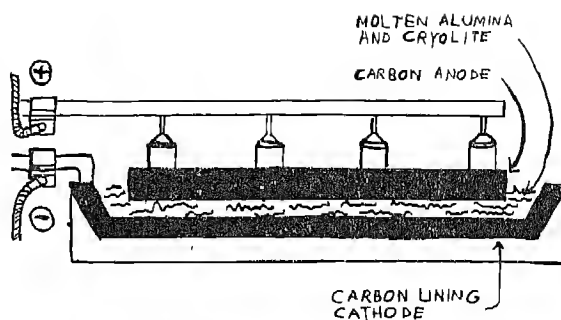

FIG 5 3   *Electrolytic extraction of aluminium*

dissolves aluminium oxide or bauxite quite easily For obtaining aluminium, electric current is passed through a solution of bauxite in molten cryolite by carbon electrodes dipped in this solution Large currents (8000-40,000 amperes) are passed at low voltage This current serves two purposes It produces heat and keeps the mass molten, it breaks aluminium oxide into aluminium and oxygen Free aluminium is heavier than the solution and therefore settles at the bottom, from where it is removed from time to time

Special Metallurgies

All metals are not obtained by the methods described above The extraction of some metals involves special treatment For example, nickel is found in ores, along with other costly metals like platinum To separate nickel from other substances, advantage is taken of a special property of this metal Nickel can combine with carbon monoxide, an extremely poisonous gas The combined product is known as nickel carbonyl $Ni(CO)_4$, which is a gas at room temperature This gas can be collected easily On further heating, it decomposes and gives pure nickel This metal has a shining appearance and is commonly used as plating on other base metals This nickel plating gives a very nice finish to the metal and is therefore used for decorative purposes. Nickel resists oxidation and corrosion, and nickel plating serves as a protective coating on many metals.

Tungsten metal, again, is prepared by reduction with hydrogen gas The most common ore of tungsten is known as wolframite The tungsten metal in this ore exists in the form of a black oxide The ore is heated with soda and then hydrochloric acid is added Thus, free tungstic acid is obtained, this can be easily separated from other impurities The solid tungstic acid is heated and a stream of hydrogen is passed over it By the action of hydrogen on the acid at a high temperature, tungsten metal is obtained as fine powder Metals in the powder form do not have many uses, they are generally needed in the form of big blocks or wires For example, tungsten wires are used as filaments in electric bulbs and radio valves. One method of changing powdered metal into large blocks can be to heat the powdered metal till it melts into one mass, which may be cooled subsequently. The trouble with tungsten is that it has a very high melting point It is, therefore, difficult and very costly to adopt this method However, metallurgists have found a more convenient way to convert tungsten powder into a homogeneous mass In this method, the powder is compressed to a very high pressure This compressed powder is then heated to a moderately high temperature, this changes the compressed powder into a block of metal at a much lower temperature than the melting point of tungsten This method is known as 'powder metallurgy'.

Another metal which is finding increasingly greater use is magnesium Magnesium is present in sea water in large amounts, and is extracted from it Large volumes of sea water are treated with lime This precipitates magnesium hydroxide, $Mg(OH)_2$, which is insoluble. The precipitated magnesium hydroxide, separated and dissolved in hydrochloric acid, produces magnesium chloride ($MgCl_2$) The magnesium chloride is melted and an electric current is passed through it to electrolyse it so as to produce magnesium and chlorine Magnesium is a light, silvery white metal which floats on the top and is taken off The chlorine is converted back to hydrochloric acid and used again Magnesium is a light metal which forms alloys with aluminium and copper. These alloys are finding use in the manufacture of aeroplanes, balances and other industrial products where light metals or alloys are needed

Alloys We have already seen that on adding small amounts of tin to copper its properties change to a great extent The resulting material is known as bronze. Bronze is an alloy Metals have the ability to mix with one another to form alloys. Alloys generally have metallic properties and are made by mixing or combining two or more elements, at least one of which should be a metal Some common alloys are described below

Brass	70% copper	30% zinc
Bronze	90% copper	10% tin
Solder	50% lead	50% tin
Steel	99.8% iron	0 2% carbon
Stainless steel	74% iron	18% chromium, 8% nickel

Steel In modern times, steel is the most commonly used alloy Many kinds of steel are made for special purposes Steel is made from cast iron There are two main methods of making steel The older method is known as the 'Bessemer Process', it was first introduced by a British metallurgist, Henry Bessemer, in the year 1856 He proposed that steel could be made from pig iron, which is the name of the iron obtained from the blast furnace. This iron contains large amounts of carbon and has poor mechanical strength. The main part, called the Bessemer converter (shown in Figure 5 4), is a container for molten pig iron The converter or
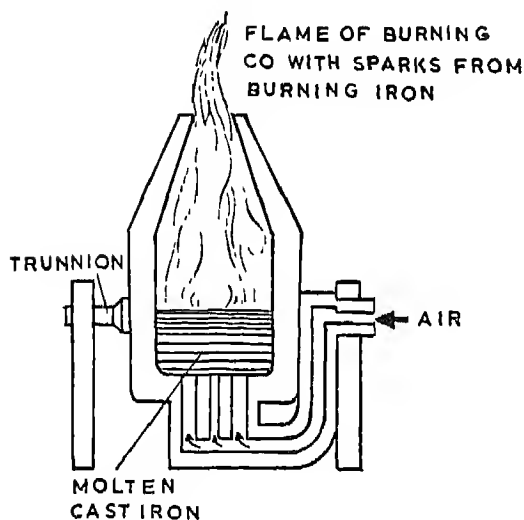

FLAME OF BURNING CO WITH SPARKS FROM BURNING IRON

TRUNNION

AIR

MOLTEN CAST IRON

FIG 5 4   *Bessemer converter*

furnace can be tilted to take in or pour out a charge of molten pig iron Air is blown through holes at the bottom of the converter, at high pressure, through the charge of molten pig iron in the converter. Due to the high temperature and the presence of oxygen of the air, the carbon in the pig iron is removed as carbon monoxide and other impurities float at the top in the form of a slag The chemical reaction causes the temperature to rise to about 1600°C. During the final stage, a white tongue of flame comes out of the mouth of the converter with a roaring

noise, the flame may be as high as 10 metres In a few minutes the carbon is mostly gone and the flame contracts This is the signal to stop the blast The Bessemer process has been further improved so as to remove the phosphorous which is very often an impurity in iron ores In 1952, a modification was tried in Austria, in which oxygen, instead of air, was blown into the converter from the top, through a tube This gave a much better yield of steel This process is now known as the 'Basic Oxygen Process' and is being gradually adopted at many places in Europe and America. The new steel plant at Rourkela, in Orissa, uses the basic oxygen process

The second major process for making steel is the 'Basic Open Hearth Process'. This process was invented by Charles Siemens The open hearth furnace contains a large, shallow, steel basin, about 50 ft long and 15 ft wide. In this basin, pig iron, scrap iron and some iron ore are placed and air is blown in at the top The process is slower than the Bessemer process but gives better steel.

BURNING FUEL

STEEL

COLD GASES

GAS OR OIL VAPOUR

GAS OR AIR

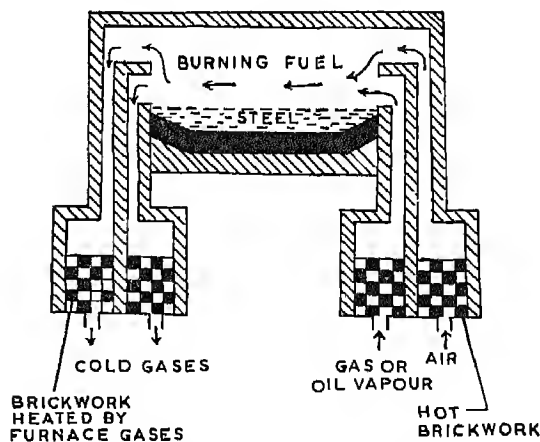BRICKWORK HEATED BY FURNACE GASES

HOT BRICKWORK

FIG 5 5   *The open hearth furnace*

In India, there are at present five major steel producing centres: Jamshedpur (Bihar), Rourkela (Orissa), Bhilai (Madhya Pradesh), Durgapur, and Burnpur in Bengal Another large steel mill is under construction at Bokaro in Bihar

It is expected that very soon India will be producing 10 million tons of steel per year.

Properties of Alloys

The modern advances in atomic energy, in the rocket industry and in transport have created unparalleled demands for new materials. This has led to the making of new alloys and metallic materials, now required for specialized jobs. Alloys have been and are being made with the desired strength, density, hardness, stability, electrical and thermal conductivity and plasticity

The properties of alloys are generally intermediate between those of the parent materials This, however, is not always true Sometimes there are dramatic changes and great deviations Generally, alloys are harder and stronger than the pure metals For example, bronze is harder than copper The electrical resistance of an alloy is higher than that of the pure metal Thus, an alloy of nickel and chromium (nichrome) is used for making the heating wires in electric stoves and toasters The melting point of an alloy, too, can be different from that of either of the parent metals For example, solder alloy is made from lead and tin, but it has a lower melting point than that of either lead or tin Another interesting alloy is that of zirconium and zinc. Neither zirconium nor zinc show any magnetic property at any temperature Only iron and, to a lesser extent, cobalt, nickel, chromium and manganese have magnetic properties A magnetic alloy normally should contain one or more of these metals. Yet it is now known that zirconium-zinc alloys show magnetic properties at low temperatures. Thus, a magnetic alloy has been made from non-magnetic substances

Corrosion of Metals

Metals often corrode in water. In sea water, corrosion is very rapid. Corrosion results in great waste of materials Similarly, rusting can be a cause of great loss of property. Corrosion can be better understood as an electro-chemical reaction between two different metals This re-

action can produce a flow of electric current such as the one we get by the dry cell used in torches. In the process of corrosion, impurities on the metal surface form a series of cells through which electric current starts flowing The metal corrodes due to this flow of current. Corrosion can also take place in wires buried in earth, and in pipes and other similar fittings New alloys are now being made, which do not corrode or corrode very little from such action

The properties of metals can also be changed by heat or heat treatment It is a common observation that a metal becomes stronger as it is slightly deformed When wires are pulled successively they get deformed When wires are pulled successively through dies having slightly smaller cross-section, they become harder When a metal piece is stamped to form a coin, it becomes much harder than the parent material. If such hardened metal is heated, it recovers its original properties This process is known as annealing

II. Chemicals in agriculture

A fertile soil is very necessary for good farming However, if a piece of land is cultivated for long periods, even good soil can become poor. In many parts of the world the soils have become poor because of erosion and exhaustive farming To prevent this impoverishment of soil the materials which have been used up by constant cultivation have to be added These materials are known as fertilizers Since ancient times fertilizers have been added to the soil, in some form or the other, e g, excreta, manure, blood, fishes, bones, decomposed organic matter, etc For a long time people believed that only organic materials are useful for the soil. Now we know that mineral fertilizers, such as nitrates, phosphates and potassium salts are also very useful and serve the special nutritional purposes of the plants.

The plants get carbon, hydrogen and oxygen from the atmosphere Certain other elements like nitrogen, phosphorus, potassium, calcium, magnesium and sulphur are also essential for

the proper growth of plants These elements get used up by plants and trees and have to be added to the soil if its fertility is to be retained, but it should be noted that these elements, as such, cannot be utilized by the plants They should be added in the form of soluble compounds which may be taken up by the plants If the soil has been cultivated for a long time, these elements have to be added back. In the long run, it is a bad policy not to return the elements which are taken away from the soil by the plants in the process of their growth

The farmyard and other organic manures are rich in some of these elements These are, therefore, beneficial to the soil But their supply is limited and, very often, they do not provide all the things needed for the proper growth of plants It is, therefore, necessary to add some mineral fertilizers such as lime, superphosphates and nitrogenous materials.

Ammonium sulphate, ammonium nitrate, potassium nitrate and urea are the chief fertilizers containing nitrogen Nowadays atmospheric nitrogen is used in the manufacture of these fertilizers on a large scale. The process of using nitrogen from the atmosphere to make useful compounds is known as 'fixation of nitrogen'. Nitrogen can be fixed by many methods The most common is the Haber's process In this process, nitrogen and hydrogen gases react to form ammonia

$$N_2 + 3H_2 = 2NH_3 + energy$$
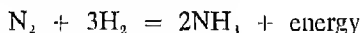
A solid agent is necessary to make this reaction go. This material is known as a catalytic agent or a catalyst A catalytic agent like spongy platinum makes the reaction go faster; yet it does not directly take part in the reaction. In India the Haber process is used for making most of the nitrogen fertilizers In Sindri (Bihar), for example, ammonium sulphate is manufactured by using ammonia (produced by the Haber's process), carbon monoxide and gypsum First, ammonia and carbon dioxide are produced, they react to form ammonium carbonate Ammonium carbonate reacts with gypsum to form ammonium sulphate In Nangal (Punjab),

a different process is used In this process, hydrogen is obtained by passing electric current through water, while nitrogen is obtained from liquid air. Both these react to form ammonia Some of the ammonia is changed into nitric acid in the presence of oxygen and a catalyst The nitric acid and the rest of ammonia combine to form ammonium nitrate Ammonium nitrate is a useful fertilizer, but in its pure form it is slightly explosive To make it safe for handling, it is mixed with calcium carbonate The product is known as nitrolime In India many fertilizer factories have recently been set up in Trombay, Kerala, Alwaye, etc Very soon, Durgapur, Rourkela and Gorakhpur will also be big fertilizer manufacturing centres These days ammonium nitrate and nitrolime are the leading nitrogen fertilizers of the world These are followed by ammonium sulphate, ammonium sulpho-nitrate, urea and anhydrous ammonia The usual raw materials for their manufacture are hydrocarbons, coal and electricity

Some soil bacteria can also fix atmospheric nitrogen Thus they also help in increasing soil fertility. During electric discharges in the atmosphere, some nitrogen oxides are formed, which are carried to the soil through rain water, as nitrous and nitric acids. These form soluble nitrates in the soil directly

Phosphates

Plants also need soluble phosphates for their proper growth. Many rocks and animal bones are rich in phosphates, but these phosphates cannot be used as such, since they are not soluble However, they can be made soluble by chemical processes If sulphuric acid is added to animal bones or rock phosphates, they change into a mixture of soluble calcium phosphate and gypsum This mixture is known as superphosphate of lime and is a useful fertilizer Nowadays improved methods of making phosphates have been developed In one of these methods, rock phosphate is treated with nitric acid By this method, nitrophosphate is formed, which contains both nitrogen and phosphate

Similarly by adding phosphoric acid to bones or rocks, triple superphosphate is formed. This is a more concentrated phosphorous fertilizer Ammonium phosphate is another useful fertilizer The basic slag is a waste product of the steel industry But this has now been found to be rich in phosphorous and is being used as a fertilizer. A fertilizer plant is being built near Kanpur which will use slag for manufacturing superphosphates It will produce 60,000 tons of superphosphates per year

Potassium fertilizers are also needed for plants Potassium chloride is very often added as a fertilizer to the soil Potassium nitrate contains both potassium and nitrogen.

Nowadays more and more fertilizers are being used, which contain more than one useful material Originally, such fertilizers were merely simple mixtures of materials like superphosphates, ammonium sulphate and potassium chloride. But now chemical mixtures are being used, which have the advantage of producing homogeneous particles containing nutrient materials This helps to ensure the balanced ratio of plant nutrients

Trace Elements

Agricultural scientists have found that certain plants need certain specific elements in trees for their normal growth. In many cases the health of a plant, flower, vegetable or fruit depends on the presence of these 'trace elements' in the soil Among such elements are manganese, zinc, copper, cobalt and barium These elements somehow act like catalysts For example, manganese is a catalyst in many reactions of enzymes. The presence of one part of boric acid per ten million parts of water stops many plant diseases Similarly, it has been found that zinc is a necessary element for citrus fruits. A deficiency of zinc causes diseases in citrus plants In some Australian soils, a small amount of copper has been found to be necessary for the proper growth of wheat. It was also noticed in Australia that if small amounts of copper salts are added to pasture land, it provides a good quality of grazing grass for sheep, which in turn yield a superior quality of wool In some other South Australian lands, it was demonstrated that by adding about 15 gm of molybdenum per acre, in the form a soluble compound, useless land could be made fertile A large number of such experiments have been conducted on Australian soils. These have demonstrated the need of trace elements for the proper growth of plants and trees However, we do not yet know all the trace elements and their function in various kinds of plant life

Sewage

People consider sewage as a nuisance Many methods have been employed for its disposal In many large cities, sewage water is dumped in rivers This leads to water pollution which is harmful and even results in the loss of marine life Such disposal is also a danger to human life Open drains are a normal sight in most of the Indian cities and towns.

It has been demonstrated that sewage can be put to better use By adding certain bacteria to the sewage water, it can be made to liberate methane, a useful fuel gas Treated sewage becomes a good fertilizer and can be usefully put in farm lands for improving plant yield At many places sewage is now being used in this manner. Certain large cities like Bombay have sewage treatment plants in operation. We need many more plants spread out all over the country, in cities as well as the countryside

Hydroponics

The art of growing plants in a soilless medium has been known for over a hundred years However, it has come into prominence only recently and is now known as hydroponics In hydroponics, plants are grown in water containing dissolved nutrient materials Tomatoes, cucumbers, beans, etc , have been successfully grown by this method Although it is not possible to grow everything without soil, much can be learnt by experimenting in hydroponics.

Insecticides, Pesticides, Fungicides and Herbicides

Chemists have done a very useful service to the farmer by providing him with means of fighting the enemies of crops, such as insects, fungi and weeds. Insects and fungi attack the crops, while weeds consume the moisture and useful materials from the soil and thus starve the plants Till about 25 years ago, most insecticides were obtained from natural sources and consisted mainly of sulphur, copper, arsenic and fluorine compounds. During the last 20 years, an impressive number of compounds have been made to meet the attack of insect pests and fungi on plants Dichloro-diphenyl-trichloro-ethane, popularly known as DDT, is a well-known insecticide.

This compound is a very potent and persistent insecticide. It can be used for destruction of insects such as mosquitoes, flies and ticks which carry germs of malaria, yellow fever, dysentry, plague, typhus, sleeping sickness, etc In 1943, during World War II, DDT was used in Naples during an epidemic of typhus It successfully stopped the epidemic over the entire affected area Another powerful insecticide is Gammexane, which is benzyne hexachloride ($C_6H_6Cl_6$). It can be used as a dusting powder or as a spray in solution Gammexane has been found to be effective against cockroaches and locusts. Two new insecticides, known as Aldrin and Dieldrin, which are now in common use, are very effective against many insects, including mosquitoes and locusts

There are some compounds containing phosphorus, which if added to the soil, can be taken up by the plants. These enter the cell sap If any insect sucks the sap, these compounds enter the insect and poison it. Such insecticides have been successfully used in controlling the spread of many disease-carrying insects on cocoa plantations.

In some cases, the seeds are treated with a special chemical before being placed in the soil.

These chemicals get into the sap-stream of the plants Any insect sucking the sap is doomed to die

Chemists have also succeeded in preparing substances which act as selective weed killers These destroy weeds and leave the crops or grass unaffected. Methoxane and 2,4-D (dichloro phonoxy acetic acid) and 2,4,5-T (trichloro phonoxy acetic acid) are very commonly used as selective weed killers

Certain bismuth compounds act as fungicides against the diseases of potatoes and tobacco To protect stored grains against the attack of insects like beetles, many fumigants have been made These fumigants poison those insects. Carbon tetrachloride, methyl bromide and ethylene dibromide are commonly used fumigants. Thus, we hope that by successful use of insecticides and related compounds, disease among men, animals and plants can be controlled, and perhaps abolished. Loss of life, as well as destruction of food, can be reduced and the battle against hunger and disease can be won

Dangers of Insecticides

It should, however, be noted that most insecticides and herbicides can be harmful to men and animals if used indiscriminately. Insecticides which persist for a long time are, no doubt, useful but they can also cause harm to good crops These insecticides are capable of destroying all living insects, some of which are useful to plant life Moreover, heavy doses of chemicals can cause a disturbance in the balance of nature by killing useful life also. Therefore, a good insecticide should not stay for very long after it has been sprayed It should decompose after a reasonable period, otherwise it can accumulate and harm the soil, and plant life. Great care and study is, therefore, needed for the correct use of these insecticides.

III. Materials in the home

The work of a housewife nowadays is considerably lighter due to the development of

chemistry Much of the hard work has been eliminated from the household chores by the use of articles made by chemists. For example, a safety match lights fire in a few seconds—something which took hours in the olden days. Gas or electricity has made cooking quite convenient. Utensils do not become dirty when put on a gas or electric fire as they do over a wood or coal fire Similarly, better cosmetics, toothpaste, soap, adhesives, detergents and varnishes are now made, these make life comfortable, clean and economical

The cleaning of clothes, rugs, utensils, floors and other articles forms a very important part of household duties The chief cleansing material is soap. It helps to remove stains, dust and dirt Soaps are usually sodium salts of natural fats or oils. An important property responsible for the cleansing action of soap is that it lowers the surface tension of water This means that it allows the water to spread out over a greasy surface, thus, a dirty cloth is thoroughly soaked and water comes in close contact with the entire greasy surface. Soap solution forms lather due to the lowering of the surface tension of water and lather washes out the dirt Further, soap emulsifies salts and fats, the film of grease is thus broken up, resulting in the dirt being washed away.

Soaps do not work well in hard water due to the formation of insoluble products. Now synthetic materials have been made which possess cleansing action and work equally well in hard water. These materials are known as detergents. They are sodium salts of sulphonated hydrocarbons Two examples of detergents are sodium dodecyl sulphate and sodium alkyl benzonyl sulphonate Synthetic detergents are prepared differently for specific purposes, such as laundry, shampoo, cleaning china and glassware, etc.

A difficulty however arose in the case of detergents because, unlike soap, they are not decomposed by bacteria If these new detergents are used exclusively for a long time, they can accumulate and pollute the underground or river water. Some European and American rivers have become foamy because of the continuous use and disposal of detergents by the people there Chemists have now tackled this problem by making 'soft detergents' which are decomposed by the action of bacteria. They are also known as bio-degradable detergents and are prepared by using straight-chain hydrocarbons. In Germany, only bio-degradable detergents are allowed to be manufactured, and the production of hard types of detergents (not degradable) has been prohibited by law

Disinfectants

For cleanliness and better health, disinfectants are needed in the home These destroy disease-producing germs and prevent the spread of infectious diseases Some of these form vapours and attack impurities and germs in the air. Others are used on the diseased part of the body or on other materials. Camphor and some oils are used as air disinfectants. Potassium permanganate, bleaching powder, phenyl, hydrogen peroxide, iodoform, carbolic acid and salicylic acid are the commonly used disinfectants The process of heating under steam pressure, or strong cooling, can also serve the purpose of disinfecting materials Disinfectants are strong chemical compounds and so they should be used with care and under medical advice. Disinfectant materials should be used only in the correct dilution. A higher concentration can be harmful to the body while a lower concentration than the required one may be ineffective for the purpose of disinfection

Cosmetics

These are materials used for the care of the body In ancient days, natural oils and related materials were the commonly used cosmetics, e g , oils from sandalwood, seeds and flowers Certain products like cornflour were also employed. Nowadays, most of the cosmetic materials are prepared artificially from minerals or petroleum products. Jellies made from petro-

18

leum are used as grease. Toilet powder is pre-
pared from hydrated magnesium silicate and is
known as talcum. Titanium oxide and zinc oxide
are used in preparing face powder. Red ferric
oxide is used for making rouge, lipstick, etc.
Cosmetics of inferior quality can be harmful to
the skin. Only products made by reputed manu-
facturers should be used. Some persons may find
that certain face powders cause irritation to the
skin while others do not. It is possible that such
persons may be allergic to certain materials
present in the powder. Another brand may not
cause such irritation.

Cosmetics do not usually require expensive
ingredients. The price often has no relation to
the cost of cosmetics. Usually it is not a guide
to quality because there may not be any differ-
ence between an expensive and an inexpensive
product. Many cosmetics can be prepared at
home cheaply.

Blue Black Ink

Many inks are made from iron compounds.
Iron forms two types of compounds ferrous
and ferric. The change of a ferric salt to a
ferrous salt is used in making blueprints, while
the change of ferrous to ferric is utilized in the
making of blue black ink used for writing.
Ferrous sulphate is added to tannic acid to make
tannate solution. When this solution is used for
writing, the ferrous iron is changed into dark
blue ferric tannate.

Ferrous tannate + oxygen (from air) →
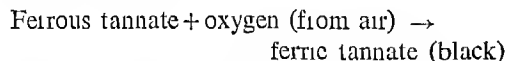
ferric tannate (black)
, There are many types of special inks. The
dhobi's marking ink is made from a nut known
as sterculia. Coloured inks are made from
organic dyes. Laundry ink contains silver nitrate.
Printing ink is made from carbon black. All
inks do not contain iron salts.

Stains caused by ink can be removed by the
use of certain chemicals. Oxalic acid, lime juice,
sour milk or sodium hypochlorite solution are
used to remove ink stains from clothes. These
materials reduce the ferric iron of the perma-
nent ink into a colourless state. To remove a
stain of printing ink, vaseline is rubbed on it.
This process softens the medium which can now
be washed with soap or petrol.

Paints

Paints are made by making pigments in
some liquid oil. Pigments are inorganic com-
pounds and oils are products of natural organic
matter. The most commonly used pigment is
white lead which is a mixture of lead hydroxide
and lead carbonate $Pb(OH)_2$ $2PbCO_3$. These
pigments are usually mixed with linseed oil.
Paints usually serve two purposes. They deco-
rate, and they also prevent rusting and the
action of air and water on materials. Normally,
paints take a long time to dry. To hasten the
process, some agents are needed. These are
known as dryers. Lead oxide and metallic soaps,
if added in small amounts, act as good dryers.
Dryers change the liquid into a solid by oxida-
tion. Sometimes paints are in a very viscous
form. Thinners are then added to give paint a
proper consistency. Turpentine is the most
commonly used thinner material. Paints can
be coloured by adding pigments, such as
chrome yellow, carbon black and venetian red
(Fe_2O_3).

Paints made from white lead can turn black
if the air contains hydrogen sulphide (H_2S).
Lithophone paints do not turn black. These are
made by mixing zinc sulphide and barium
sulphate. Titanium dioxide is also used as a
white pigment and as a base for some coloured
paints.

Glass

Glass is a fused mixture of certain silicates.
Since the earliest times, man has known the
art of glass making. Glass beads have been
found in Egyptian tombs which are 6000 years
old. Glass making as an art was known in
ancient India. It is interesting to note that glass
is not a true compound. Common glass is made
from a mixture of sand, sodium carbonate and
calcium carbonate. The mixture is heated and
the molten mass is cooled rapidly. The making

of glass may be represented by the following equation

$$Na_2CO_3 + CaCO_3 + 6SiO_2$$
$$= Na_2O\ CaO\ 6SiO_2 + 2CO_2$$
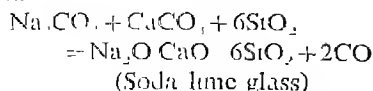
(Soda lime glass)

During glass making, carbon dioxide is set free Soda lime glass is used in making bottles and glass sheets Special glasses are made by adding different metallic oxides or carbonates For example, lead oxide is added to make electric bulb glass Potassium carbonate is used for making optical glass Aluminium oxide and boric oxide are used for making laboratory glassware

Coloured glasses are made by adding small amounts of metals or their oxides to the molten mass of glass Thus, for getting a blue glass we add cobalt oxide. Similarly, chromic oxide is added to get a yellow-green colour Small amounts of colloidal gold give a beautiful ruby-red glass It is the ions of the added metal which give colour to the glass

Glass is a brittle compound and will shatter into small pieces when struck. The brittleness of glass is dangerous in the case of the wind shields of cars, etc Shatter-proof glass has however now been made. Two pieces of glass are joined together with an adhesive layer of cellulose acetate or some other transparent plastic material, and heat and pressure are applied to fuse them together When such a glass is struck, it does not break into pieces; only cracks appear

Foam glass is a light material It is made by heating a mixture of crushed glass and carbon

Glass is widely used in the home and in industry Glass bricks are used in modern buildings Glass panes are used in doors Foam glass is used widely in ship-building and in making buoys and other floatation equipment. Fibrous glass is used for sound, heat and electric insulation

Mirror

A mirror is a glass plate with a coating of a light-reflecting substance, e g, silver,

gold, aluminium or lead sulphide Before silvering, the glass is cleaned and polished It is then treated with a solution of formaldehyde or some other reducing compound Immediately, a solution mixture of silver nitrate and ammonia is poured over the glass and left for about an hour The silver nitrate reduces into a thin film of metallic silver Over this, a protective coating of paint is done Sometimes the coating is done either by spraying or by condensing the vapours of the material

IV. Chemicals in industry

Sulphuric acid is the most important single industrial chemical compound The amount of sulphuric acid used in a country is sometimes used as a yardstick of its industrial development It is used as a raw material for making other acids and a large number of organic and inorganic compounds The manufacture of sulphuric acid often starts with sulphur dioxide This is obtained from the roasting of the sulphide ores such as the iron pyrites and copper pyrites mentioned in the discussion on the extraction of metals For a long time sulphuric acid was manufactured by the 'lead chamber process' Sulphur dioxide, steam and the oxygen of the air react in a large lead chamber in the presence of oxides of nitrogen These nitrogen oxides act as catalytic agents The lead chamber process is slow and produces dilute sulphuric acid. In advanced countries this process has been replaced by the 'contact process' In this process, sulphur is first burnt in a furnace to get sulphur dioxide This is mixed with air and passed through a converter to form sulphur trioxide. The converter is a large chamber containing the catalytic agent (a mixture of vanadium pentoxide and platinized silica gel). Finally, sulphur trioxide passes through the absorption tower where it changes into sulphuric acid

The contact process is rapid and is practically automatic However, in India most of the sulphuric acid is still manufactured by the chamber process.

Sulphuric acid is needed in producing ferti-

lizers It is also used in the manufacture of metals. The salts of sulphuric acid have many uses for industrial, domestic and medicinal purposes The petroleum industry and the synthetic fibre and other industries use large amounts of sulphuric acid

Petro-chemicals

Petroleum and natural gases are raw materials for many synthetic products. The nature of petroleum has already been described in the chapter on minerals The petroleum industry has given rise to a number of by-product industries. Nowadays many products, such as methanol, acetic acid, acetone, glycerine, etc., which were prepared from natural products like wood by fermentation, are being made from petroleum products. Most of the insecticides are now made from petroleum gases Petro-chemicals are employed for the manufacture of artificial fibres and cloth, celluloid, photographic film, artificial leather, synthetic rubber, etc Useful medicines, like antibiotics and diuretics for curing kidney and heart troubles, are being made from the by-products of the petroleum industry.

In India a number of petro-chemical industries are being set up The petroleum refineries at Bombay, Visakhapatnam, Assam, and Bihar and in South India are giving rise to useful by-product industries In many big cities, petroleum gas (like Indane or Burshanc) is now available in cylinders for cooking purposes

Mica

Mica is composed of a group of widely distributed minerals. They are easily split in a single direction and possess great flexibility and strength The composition of mica is variable It is made of complex silicates Mica is found in large quantities in Bihar, Andhra Pradesh (Nellore) and Rajasthan Mica is transparent and resistant to fire Owing to this useful property it is widely used for windows in stoves and lanterns, and peep-holes in furnaces. Mica is a bad conductor of electricity and so is used for insulators in electric gadgets.

The mining of mica is an important industry in India but, unfortunately, scientific methods are not employed and mica is still obtained through crude methods Thus a large amount of mica is damaged during the process of mining Large blocks of mica are split into sheets and cut to size with a sharp knife The larger the size of a mica sheet, the greater is its value.

Cement

Cement is the most commonly used binding material For a long time, cement has been used, in one form or the other, in building structures The most common form is known as Portland cement It is a mixture of calcium silicate and calcium aluminate It is made by heating a mixture of graphite, clay and limestone The mixture is put in a large, inclined, rotating cylindrical kiln Powdered coal, oil or gas is heated at the bottom of the kiln The mixture slowly flows from the top and meets the flames as it comes down Hard masses of cement are formed These are cooled and crushed into a fine powder

$$5CaCO_3 + 2HAlSiO_4$$
$$= 2CaSiO_3 + Ca_3(AlO_3) + 5CO_2 + H_2O$$
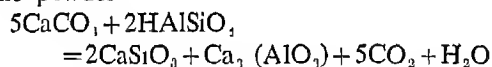
Cement is a good mortaring and bonding material Ordinary lime cannot bond with iron whereas cement can bond with iron and stone to make reinforced concrete Reinforced concrete is superior to concrete as a building material. Hence reinforced concrete is widely used in making roofs, pillars and foundations of structures Modern architecture requires reinforcements of special types These can only be given by cement When dry cement is mixed with water, it hardens in a couple of days Special cements are made for specific purposes For example, quick-setting cement can harden in a few hours White cement is used for decorative purposes on floors and walls

Graphite

Graphite is a crystalline form of carbon. It possesses lustre and is a good conductor of electricity It also possesses lubricating properties. Modern industry has a large need for

graphite Not much graphite is found in nature as such, and so most of it is prepared artificially The process of manufacturing graphite is known as Acheson's process

In Acheson's process, anthracite coal is heated to a high temperature in an electric furnace which is covered with sand. At this high temperature, coal is converted into graphite This process needs a large amount of electricity and can only be profitable if electric power is cheap

Graphite has many uses in our day-to-day life It is used in making lead pencils (These actually do not contain any lead) Graphite is also used as a lubricant in many industries Graphite electrodes are used in the manufacture of aluminium and in electrical furnaces Dry batteries also use graphite electrodes.

Diamond is also a form of crystalline carbon It is the hardest substance known in nature, and is used in drilling holes in hard surfaces Diamond particles are used in the watch-making industry Recently, small diamond pieces have been made artificially from graphite at a number of laboratories in the U S A , Sweden, France and the U S S R.

V. Fuels

Fuels are the chief source of energy for the home and for industry. Fuels can be solid, liquid or gaseous Coal is the most important solid fuel Petroleum is a liquid fuel while natural gas is a gaseous fuel. These fuels have been dealt with in the chapter on minerals The supply of fuels in the world is limited For example, so much petroleum and its products are being used these days that it may be exhausted in less than fifty years Attempts have therefore been made to prepare synthetic petrol from coal, although the cost of preparing it from this source until now has been high. Coal is changed into petrol or gasoline, and the process is known as coal hydrogenation A simple equation for this change can be written in the following manner:

$$7C + 8H_2 \longrightarrow C_7H_{16}$$
Coal + hydrogen $\longrightarrow$ petroleum gasoline
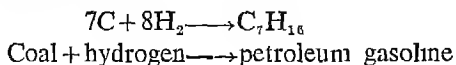
In this process, a stream of powdered coal is subjected to high heat and pressure in the presence of superheated steam and oxygen By this treatment, a mixture of carbon monoxide and hydrogen is formed This mixture is then heated in the presence of a powdered iron catalytic agent. By this method, both diesel oil and petrol are prepared This process was first introduced in Germany by Franz Fischer and Hans Tropsch, and is known as the Fischer-Tropsch process. During World War II, large amounts of synthetic petrol were made in Germany when its supply of natural petrol was cut off

Sometimes alcohol is added to petrol to increase its quantity without decreasing its fuel value The product is known as power alcohol

Natural gas is a very useful fuel and occurs with petroleum deposits in underground soil It chiefly consists of methane (CH_4) gas. Large amounts of natural gas are used for cooking, heating and industrial purposes

If coal is heated in the absence of air, coal gas is produced Like natural gas, this is also a useful gaseous fuel and has been used for street lighting for a long time Even now, some streets in Calcutta are lit by this gas Certain fuel gases are made by passing air or steam over heated coal When air is passed in a limited amount on heated carbon, a mixture of carbon monoxide and nitrogen is obtained This mixture is known as producer gas. Producer gas is a poor quality fuel, but it is widely used due to its low cost When steam is passed over superheated coal, another fuel gas, known as water gas, is obtained This is a mixture of carbon monoxide and hydrogen Water gas is extensively used in steel welding and in other industries Although it produces a small flame, the temperature is high

New Fuels

During the last 20 years, a new source of energy has been discovered by man This is popularly called atomic power; more correctly, it is the power obtained from the fission of

uranium. The power of fission of uranium has nothing to do with oxygen or burning Pure uranium metal, arranged in a geometrical way in clean heavy water or pure graphite, will spontaneously lead to the splitting of uranium atoms, if the entire size of the arrangement is increased beyond a certain minimum. When the fission of uranium takes place the pure uranium rods get hot, and this heat can be extracted and used This arrangement of uranium and heavy water or graphite (called a reactor) acts therefore like a furnace which converts the energy of the fission of uranium into heat. This heat is used for producing electric power at a number of places in Japan, Europe and America

In India, a big power house run by atomic energy is being set up at Tarapore near Bombay, and a second one at Rana Pratap Sagar in Rajasthan Direct production of electricity from atomic energy has been tried in some artificial satellites by the United States of America

Rocket Fuels

Recently, many solid and liquid compounds have been utilized to propel rockets The science of rocketry is developing very fast and it has made new demands on fuels Some of the fuels used in rockets are hydrazine, nitric acid and boron compounds

VI. Explosives

Explosives are those substances which are capable of exerting sudden pressure on their surroundings This pressure is caused as a result of the sudden liberation of hot gases or volatile substances possessing a large volume. The substance or substances which make up explosives remain unchanged under ordinary conditions but undergo a fast chemical change on stimulation The process is exothermic, which means that it liberates a large amount of energy The energy is usually in the form of heat. As has been mentioned earlier, an explosive can be a single compound or it can be a mixture of substances.

Explosives may be solids, liquids or gases They can undergo chemical changes by heat, burning, an electric spark or a mechanical blow All explosives undergo chemical changes when heated to a sufficiently high temperature Some explosives are made to work by a sufficiently violent mechanical blow. They can also be ignited by an electric spark Two types of actions can take place with explosives One is known as deflagration, i e , violent burning The second is known as detonation, this results in a sudden blast In deflagration, the reaction is accompanied by a flame but pressure is not developed In detonation, the chemical reaction spreads like a wave from the point where it starts This results in a sudden blast, associated with sound.

Types of Explosives

Gunpowder, the earliest explosive, was first made in China more than 1000 years ago For a long time it was the only commonly used explosive It is a mixture of carbon, sulphur and potassium nitrate On its ignition, tremendous volumes of gas and vapours are produced, all at once Gunpowder was mainly used as a propellant in cannons and guns Due to the discovery of better propellants, it has now become obsolete. However, it is still used in fireworks

Gun-cotton or nitro-cellulose is another example of a modern explosive It is prepared by making cotton react with a mixture of concentrated nitric and sulphuric acids. Actually, it is a mixture of di- and tri-nitro-cellulose.

Nitro-glycerine is another powerful explosive made by the action of nitric acid on glycerine

A Swedish chemist, Alfred Nobel, used nitro-glycerine to make dynamite Dynamite is prepared by absorbing nitro-glycerine in a fine clay known as Kieselguhr Different types of dynamites are made for specific purposes, such as straight dynamite, gelatine dynamite, ammonia dynamite and blasting gelatine. Dynamite is mainly used in industrial blasting, like blasting tunnels, quarries and rocks. Dynamite, being a solid, can be used with greater safety than liquid

nitro-glyceiine. Nobel earned a fabulous amount of money by selling dynamite to the different countries of Europe He dedicated part of his profits towards the establishment of a fund for giving prizes for outstanding contributions in physics, chemistry, medicine, mathematics and literature, and towards peace These prizes are known as the Nobel Prizes

Trinitro-toluene or TNT is a high explosive It is very widely used as a propellant for bullets, artillery shells, grenades and other high explosive bombs It is prepared by the action of nitric acid on toluene TNT is employed as a standard in evaluating the power of other explosives

Explosives are detonated by means of shocks These shocks are produced by even more sensitive compounds known as detonators Mercury thiocyanate or fulminate of mercury Hg(CNO) is a widely used detonator. Lead azide, $Pb(N3)_2$, is another detonator Detonators are used in making caps for shells and other devices

A large factory has been set up in Gonna (Bihar) to manufacture nitro-glycerine India is now self-sufficient in blasting and other common types of explosives.

VII. Polymers

A new class of compounds known as polymers are now widely used Polymers have great economic importance these days and this will increase in future because of their cheapness, variety and versatility. In a way, polymer molecules are similar to simple molecules, they are built up of repeated units of many small molecules These units of small molecules are held together by covalent chemical bonds. When the number of such repeated units exceeds 100, the molecule is known as a polymer.

All polymers are not man-made In nature we have many examples of polymer molecules. For instance, starch, cellulose and proteins are natural polymers These consist of large molecules It may be interesting to note that cotton, silk and hair are examples of very large natural polymers. Of the plant fibres, cotton is one of
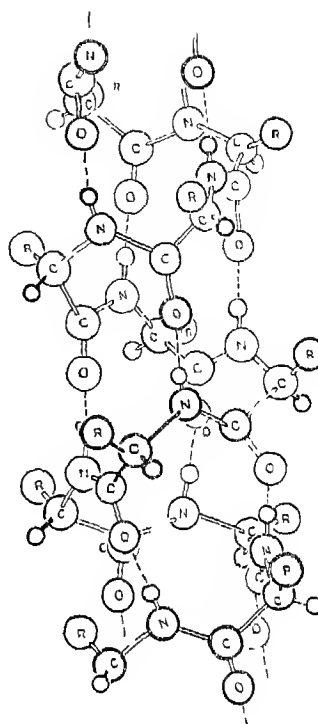

Fig 56   Protein molecule

the most widely used in the manufacture of textiles Cotton fibre is almost pure cellulose Its formulae can be roughly represented as $(C_6H_{10}O_5)_n$, where n is a very large number. These molecules are long chains of glucose molecules and are bound through oxygen atoms in such a manner that they are roughly in a straight line Cotton fibre is not affected by an alkali solution but can easily be attacked by strong acids When cotton fibres under tension are put in a cold concentrated solution of caustic soda, they become smooth and shiny Such treated cotton is known as mercerized cotton

The hair of sheep is known as wool Wool is made up of protein material, and is by far the most widely used animal fibre If a wool fibre is observed under a microscope, it appears to be circular or as having a saw shape. The fibre generally coils like a spring and can therefore be stretched easily Wool can dissolve in caustic soda solution but it is not easily attacked

by acids Wool textiles are warmer than cotton because of their property of having a large number of air cushion packings in between the wool fibres Air is a bad conductor of heat and so it does not allow the heat inside the body to get inside the air packings in the wool easily

Silk fibre is made by caterpillars of an ashy white moth which feeds on the leaves of the mulberry tree It spins the thread from a viscous liquid which it squeezes out from its body. By scientific methods, the yield and quality of silk has been greatly improved. Silk is made up of protein material Natural fibres do not always possess all the properties needed by man. Therefore, for a long time people made an effort to artificially make fibres resembling silk. In the nineteenth century, a Frenchman by the name of Chardonnat found out a method for making artificial silk. He first prepared a solution of a cellulose compound in vinegar Then this solution was forced to pass through small holes into a tank of alcohol. By this unusual process, long and thin fibres could be made, these were called artificial silk. This process marked the birth of the man-made textiles industry More than thirty different countries manufacture artificial textiles today. Cellulose produced in this way is known as rayon. Nowadays, artificial silk is made by several methods Cellulose is obtained from trees, bark or low quality cotton This is dissolved in various solvents like carbon disulphide (CS_2), etc. The solution is forced through holes into an acid bath which consists of sulphuric acid and sodium sulphate. The solution at once changes into a thin solid filament These filaments are twisted into thread by revolving spindles By this process, not only fibres but also sheets of rayon can be made

However, rayon is not a completely synthetic fibre. It is made from dissolved cellulose which is a natural product and a very complex organic molecule Scientists have been trying to make a completely synthetic fibre. In 1939, the American chemical company, E I. du Pont, announced that they had succeeded in making

a fully synthetic fibre from petroleum, coal, air and water. This fibre was named nylon Nylon is stronger and more elastic and less affected by water than silk or other natural fibres Nylon is made from two simple molecules· hexamethylene diamine, $NH_2(CH_2)_6 NH$, and adipic acid, $HOOC (CH_2)_4 COOH$. These two compounds can be combined to form long-repeating units of two simple molecules The product is known as nylon polymer. In the beginning it is obtained as a thick mass This is then forced through tiny holes to form nylon fibre The production of nylon resulted in a minor revolution in the textile and hosiery market since it had better properties than natural silk In the beginning, it was mostly used for making hosiery for women Later on, it came to be used for making shirts, dresses and other apparel Today many other synthetic fibres are being produced They have properties similar to those of nylon, but have different trade names.

One such fibre is made from the units of a small molecule known as acrylonitrile. The raw materials needed for this fibre are natural gas, ammonia and air. The common trade name for this fibre is orlon Another fibre, dacron, is made from two chemicals obtained from crude petroleum. These chemicals are ethylene glycol and terephthalic acid Dacron has a strong texture. It resists water and dries quickly Clothes made from dacron need very little ironing. Terylene is another name for this fibre Many other fibres have been made, with a few minor changes, from those described above. The U.S.A is the biggest manufacturer of synthetic fibres. Almost all European countries have big synthetic fibre industries Japan is one of the largest manufacturers of synthetic fibres.

Polymers made from simple organic compounds like hydrocarbons are being used as substitutes not only for fibres but also for other materials of day-to-day use, such as glass, metals, rugs, etc. Moulded objects and household utensils are being made in very large amounts from a compound called polyethylene.

Polyethylene has replaced many common materials For example, rubber was used for a very long time for making tubes, as it has elastic properties But nowadays more and more tubes are being made of polyethylene These tubes have better properties and last much longer than the ordinary rubber tubes. A polyethylene tube can even be transparent, so that we know the substance that is flowing inside it Polyethylene tubes are chemically inert and do not crack easily; this makes them more useful in scientific laboratories They have various trade names, such as tygon, polythene, etc

Today a great change has come in the art of interior decoration. For a long time rugs and other jute materials were used as floor coverings. But these days synthetic materials which are commonly known as polyvinyls are being manufactured and used for this purpose These materials are made from unsaturated simple hydrocarbons, such as vinyl acetate, acrylonitrile and styrene. Polymers make very good floor coverings They can be given beautiful colours and so have a decorative value Moreover, they can be easily washed with water and soap or wiped with a moist cloth or soap solution

Plastics

Plastics is a general name for a large group of substances These substances can have different origins, but they have a common property: they can be given permanent shapes These shapes may be given by a number of methods, such as heat, or pressure, or both. For a long time celluloid was the only commonly used plastic material This was made by the action of nitric acid on cellulose. Cellulose is a natural product and has already been described earlier. By the action of nitric acid, it changes into nitro-cellulose. Nitro-cellulose has been used as a plastic material. Similarly, other types of cellulose, such as cellulose acetate or ethyl cellulose, can also make plastic material. For a long time Japan was the chief manufacturer of celluloid. However, celluloid is not a completely synthetic material.

Plastic materials are now prepared from simple organic compounds Thus they are completely synthetic materials For example, bakelite is a polymer product of phenol and formaldehyde We often see household utensils, decorative pieces and toys made of bakelite Another such material is vinylite It is a polymer product of vinyl derivatives. Polystyrene polymers are made from styrene These are commonly known as styron

Plastics are usually not affected by ordinary chemicals Even chemicals which affect metals and alloys have little or no effect on plastics Transparent plastics are good substitutes for glass but their transparency decreases slowly with time If used for a long period, they do not look so clean Chemists are trying to make better plastics which may look as good as glass

Rubber

Rubber is so very commonly used that most of us do not ever think about how we get it In the home, we use rubber as floor coverings, as waterproof material, and for a number of sanitary purposes In factories, rubber gloves are a common sight. In India, rubber shoes are very useful. Rubber tyres are an essential part of any moving vehicle Students use rubber erasers It would be difficult to enumerate all the uses of rubber It is one of the essentials of our industrial age But rubber has to undergo many changes before it comes to us as a finished product Rubber is a plant product, and Malaya has the largest number of rubber plantations. In India, Kerala has some rubber plantations New plantations of rubber are now being introduced in the Andaman and Nicobar islands When a cut is made in the trunk of a rubber tree, the sap comes out, this is known as latex. A molecule of latex rubber is made up of thousands of small molecules of a colourless liquid known as isoprene These molecules are joined together in such a way that a single molecule of very great length is made. We can say that the molecule is built up as a chain.

19

Raw rubber is soft and sticky When it is heated, it becomes still softer It has little strength and is not durable Rubber in the raw state is not suited for making materials which are subjected to wear and tear However, when sulphur and rubber are mixed and the resulting mixture is heated, rubber changes its properties and becomes hard and elastic This process is known as vulcanization In this process, the long chains of rubber molecules are connected to one another at a number of places through sulphur atoms.

Small amounts of other substances are added at the time of vulcanization, such as carbon black, zinc oxide, lead oxide, and calcium and magnesium carbonates. By changing the amounts of these materials, different types of rubbers can be made By this method, rubber with any desired set of properties can be prepared.

Synthetic Rubber

Rubber plants can only be grown at certain places in the world. Countries not producing rubber naturally depend on the supply of rubber from these sources In an emergency situation like a war, such supplies can be cut off This actually happened during World War I and World War II. Therefore, many countries tried to make materials possessing the properties of rubber For example, during World War I, the Germans made a rubber substitute known as buna Later on another substitute was made in America, this was known as neoprene. Neoprene was prepared from a compound known as chloroprene ($C_4 H_5 Cl$). The structure and properties of neoprene are like those of natural rubber During World War II, a rubber substitute was made in the U S A , known as buna-S. Buna-S rubber was prepared by polymerizing a mixture of styrene and butadiene Another substitute is known as butyl rubber It is made from isobutylene and isoprene at low temperature

When World War II ended, the supply of natural rubber was resumed from Malaya. People thought that the synthetic rubber industry would not prosper because of competition from the cheap natural rubber But this did not happen On the contrary, synthetic rubber production continued to increase For certain types of use, synthetic rubbers are better than the natural rubbers They are less affected by chemical changes than natural rubber And chemists are now making even more products which possess the required properties. Although the rubber tree is still the chief supplier of rubber, the synthetic rubber industry is here to stay

The manufacture of synthetic rubber has now been started in India A large synthetic rubber plant is in operation near Bareilly in Uttar Pradesh It produces over 20,000 tons of synthetic rubber per year The raw material for making rubber is the alcohol obtained from the molasses which are found in large amounts in the sugar mills of that area Importing an equivalent quantity of synthetic rubber from foreign countries would have cost India nearly Rs. 5 crores of foreign exchange, this money is now being saved by the production of synthetic rubber in this factory. Another synthetic rubber factory is under construction near Bombay

Astronomy

From time immemorial men have gazed at stars and have tried to study them The study of stars is called astronomy and can be roughly divided into (*a*) Astrometry, the study of the positions and motions of the stars as well as other heavenly bodies, and (*b*) Astrophysics, the study of the structure, constitution and development of these celestial bodies. The solar system which we mentioned earlier is comparatively near, and easier to study If we think of the sun, our nearest star, as being about one metre in diameter (actual diameter 1,370,000 km/860,000 miles), the earth is about 11 metres away, Pluto, the farthest planet, is nearly 3 kilometres away, and the distance to the nearest star is about 25,000 kilometres The distances are so vast that it is quite difficult to comprehend them Kilometres or miles are inconvenient units for such vast distances Astronomers therefore use other units of distance One of these units is the light year (1 light year = 300,000 × 365 × 24 × 3600   km = 9.5 × 10^{12}   km) or the distance travelled by light in one year

The celestial bodies, such as stars, planets, the sun, or nebulae are far away Our method of study is to observe the light that comes from these bodies, with the help of instruments [1] Of these instruments, the most important is the telescope Telescopes made of mirrors and lenses have been in use for 300 years. The light-gathering power of a telescope depends largely on its diameter which defines, very often, the size of a telescope The amount of light that a telescope can gather defines its ability to 'see' faint objects Telescopes are mounted in various ways, so that they can follow the stars that are being observed. Modern telescopes are mostly used to take a photographic record of the skies The time required for exposure ranges from a few minutes to several hours Due to the motion of the earth, the stars seem to us to be moving If the telescope is not moved, so as to keep the image of the star in the same position on the photographic plate, the exposure appears as a blur or a streak, on developing, and not as a dot The telescope locates the position of a star and its brightness (or the amount of light that we receive from it) The light from a star can also be estimated by using a photometer The quality of the light also tells us a great deal about the star The light from a star, concentrated by a telescope, can be passed through a spectroscope (a light analyser) to find out the spectrum or the analysis of the star's light The spectrum can be interpreted to tell us something about the temperature and the elements present on the surface of the star It can also tell us if the star is moving away from us or coming towards us.

There are, however, limitations in the deduc-

[1] This is no longer strictly true of the moon and the planets, Venus and Mars Scientists, mainly in the U S A and the U S S R , are attempting to study these bodies by unmanned instruments, and later possibly by manned instruments, from rockets sent through space to these bodies or near them.

tions that can be made from these observations. A star or our sun emits radiations over the whole range of the electromagnetic waves, from the longest to the shortest In the long wave length region, our sun radiates electromagnetic waves somewhat like a group of transmitters covering a large range of wave lengths, from several metres to a fraction of a millimeter. The sun and the stars emit heat, light and ultra-violet radiations of increasingly shorter wave lengths, down to the region of X-rays Most of these radiations, however, cannot reach the surface of the earth through the atmosphere. Most of the ultra-violet rays and X-rays are absorbed by the atmosphere, allowing visible light and a small amount of ultra-violet radiation (up to 2000° A) to pass through the atmosphere to our instruments In the long wave length region below light, the atmosphere absorbs a large part of the heat radiation and some of the radio waves. The atmosphere however is fairly transparent to radio waves There is a layer of ionised gas above the atmosphere, called the ionosphere, which reflects radio waves quite easily, allowing only rather short waves, of about one metre wave length and below, to pass through This allows us to observe these radio waves from stars by means of receiving systems called radio telescopes The radio telescope is less than thirty years old —a comparatively recent invention The radio telescope looks at stars and celestial objects from a different set of wave lengths than the optical telescope The two instruments are often thought of as looking at the sky through different windows, enabling us to get two views of the same celestial objects. Although a recent tool which has been in vigorous use for less than twenty years, as compared to the 300 years of the telescope, the radio telescope has helped us to discover new objects and to change our views about some of the well-known objects in the sky The ability of a telescope—optical or radio—to 'see' faint objects depends on the 'light (or radiation) gathering' power of the telescope. This is roughly the area of the
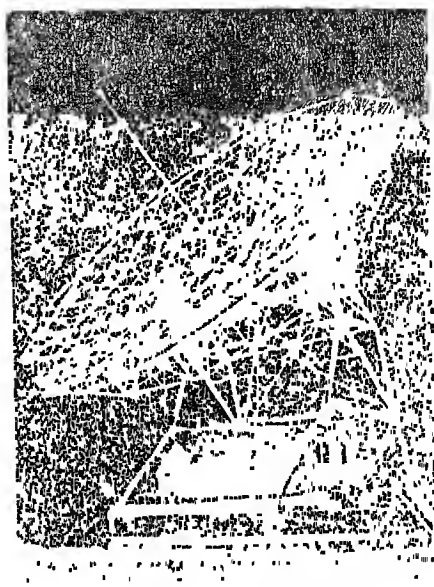

FIG. 6.1. *Radio telescope*

primary radiation gathering system In a reflecting telescope, the area of the parabolic reflector determines 'the size of the telescope' The diameter of the parabolic mirror of the telescope at Mt Palomar, the biggest optical telescope of today, is 200 inches This telescope can see an object which is 400,000 times fainter than the faintest object that can be seen with the average unaided eye. Through a 20-inch telescope, we will be able to observe objects which are 4000 times fainter than the limit of human vision A 200-inch telescope observes objects which are 100 times fainter than those seen by the 20-inch telescope Radio telescopes are tremendously large in size, their diameters are often measured in metres whereas the diameters of the ordinary telescopes are measured in inches or centimetres The reasons for the large size of the radio telescope are: (*a*) the electronic instruments which detect these lower frequency electromagnetic radiations collected by radio telescopes are not as sensitive as the eye or the photographic plate, (*b*) since the wave lengths are many times larger, the collecting system has to be correspondingly large to avoid

diffraction and interference effects. Recently artificial satellites put into orbits outside the atmosphere have excited astronomers with the possibility that these satellites could be used as astronomical observatories outside the blanket of the earth's atmosphere When this comes about it will be possible for scientists to make observations in all regions of the optical spectra now cut out by the atmosphere, and particularly in the ultra-violet and infra-red regions of the optical spectrum The ultra-violet regions of the optical spectrum of the stars are of particular interest, they not only provide additional information, but are also expected to answer some of the outstanding questions of astronomy, cosmology and astrophysics

The sun is easy to study We depend on the sun, directly as well as indirectly, for energy, light, heat and even life itself The study of the sun's surface places its temperature at about 6000°C Its diameter is 860,000 miles (1 3 million km) and it has an average density which is one and a half times that of water The density however varies greatly from the extremely rarefied gases at the exterior to the intensely compressed gases at high temperatures in the interior The spectrum of the sun tells us that it is mostly composed of hydrogen, but almost all the well-known elements on earth are present in the sun Some of these elements are present in a highly ionised state The temperature and pressure of the central part of the sun can be calculated from a knowledge of the surface temperature and the conductivity of the gases that constitute the sun Since all gases at high temperature display very similar behaviour, it is possible to deduce that the central part of the sun is at temperature of about 20,000,000°C Under these conditions, the atoms will be stripped of most of their electrons and the kinetic energy of thermal motion will be equivalent to that derived from acceleration by thousands of volts. At these high energies, and because of the crowding of the nuclei at the tremendous central pressures, there will be many moving collisions between the hydrogen atom
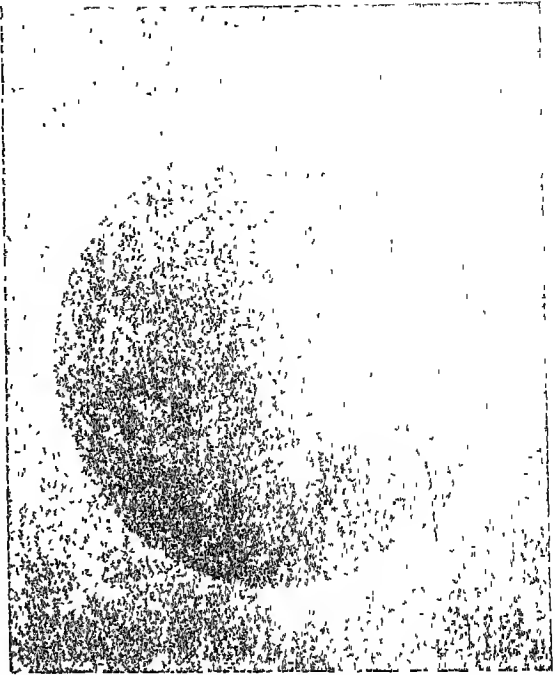

Fig 6 2   *Solar corona*

nuclei and the various other atomic nuclei in the region of the sun Two scientists, Hans Bethe and Carl von Weizsacker, proposed a certain cycle of nuclear reactions due to these collisions, which convert hydrogen into helium and in the process yield a large amount of energy According to their theory, four hydrogen atom nuclei are converted into one helium atom nuclei in several successive stages, and in the process yield energy in the form of radiation Carbon and nitrogen are the only other elements necessary for the operation of this cycle, and they are not in any way altered. This suggested series of reactions is generally accepted not only in the case of the sun but in a large majority of stars also as the source of their tremendous energies The sun, and probably most of the stars that we see, obtain their tremendous energies in the process of transforming hydrogen into helium in their interior regions. This process takes place very slowly

and explains why the sun (and, possibly, most of the stars) remain at more or less the same temperature, radiating roughly the same amount of energy for millions of years The evidence gathered from the surface of the earth tells us that the earth's temperature has not changed very much during the last three or four hundred million years, possibly longer This means that the temperature of the sun has not changed appreciably during this period of several hundred million years It has been calculated that the transformation of hydrogen to helium can keep the sun at about the same temperature for over 10,000 million years At this rate, about 4 million tons of solar matter is being converted into energy every second to keep up this radiation.

The sun radiates energy in a large range of wave lengths, and in large amounts The total energy received by the earth from the sun is much less than one hundred-millionth of that radiated by the sun This energy is distributed over a large range of wave lengths The total energy received per square centimetre of the earth's surface is 1 94 gramme calories per minute This enables us to estimate the surface temperature of the sun to be around 6000°C

The sun however does not have a uniformly hot surface Looking at the surface of the sun through very dark glasses, even with the naked eye one can distinguish small areas or spots which look dark in comparison with the rest of the surface These are called sunspots They appear in many sizes and shapes Their intensities vary, and sometimes they appear or disappear. Careful studies have shown that these areas of violent motion are perhaps somewhat cooler than the neighbouring areas of the sun The storms in the area of these sunspots are gigantic Several phenomena, such as strong magnetic fields and the ejection of electrons and atomic nuclei of hydrogen and of some of the light atoms, take place in these In India, the study of the sun is carried out at the Kodaikanal and Nainital Observatories.
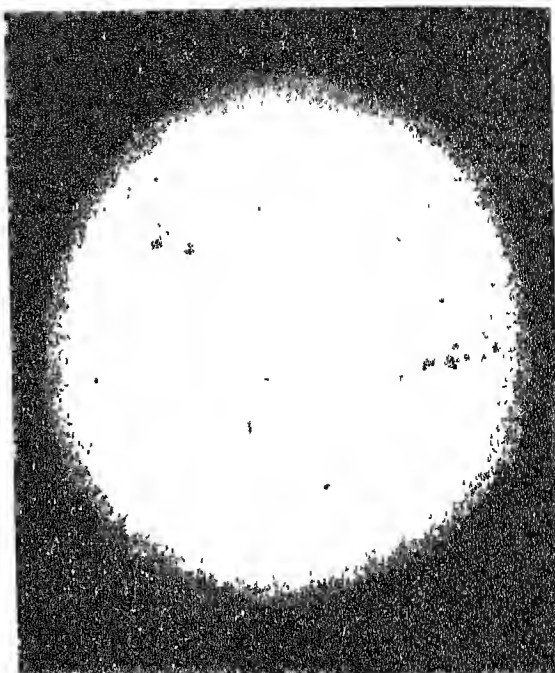
The moon is the nearest celestial body to

FIG 6 3. *The sun and the sunspots*

the earth (380,000 km) The dark markings on the moon, observed through a telescope or even high-power binoculars, reveal that there are hills, craters, valleys, cracks and depressions on the lunar surface Photographs taken from short distances by the rockets sent to the moon have revealed in greater detail the nature of the lunar surface There is no lunar atmosphere at all and the surface gets very hot under direct sunlight When the lunar surface is completely on the dark side, it becomes very cold (less than $-200°C$) These extreme temperatures and the absence of air would make the moon an uncomfortable place to live in. However, as there has been no air or atmosphere, very few changes have taken place in the lunar surface since it was first formed, except for meteors which have crashed on the moon at various times. Scientists, therefore, are inclined to think that a close examination of lunar geology and mineralogy can tell us something about the
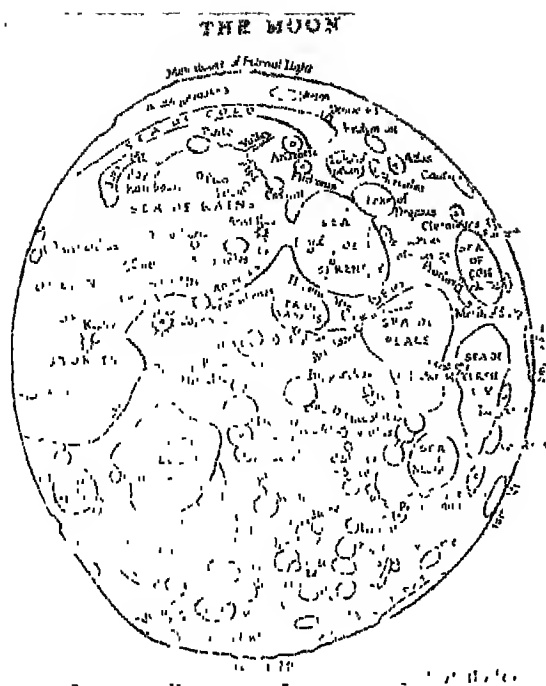
FIG 6 4   *A map of the moon*

conditions under which the moon, and perhaps the earth, was created

Next to the sun and moon, the brightest object in the sky is the planet Venus, often called the morning star or the evening star It is seen just after sunset in the western sky or before sunrise in the eastern sky. Venus is the nearest planet to the earth. Jupiter is the largest

among the planets and has a mass 1047 times smaller than that of the sun The surface temperatures of these planets are small and vary considerably Mercury has a temperature of 410°C, Venus, 80°C; and Earth, 25°C The temperature decreases as we go to the other planets The planets are dark bodies and reflect light from the sun The arrangement of planets, their size, and distance from the sun are shown in Table 6 1 below

We do not know whether other stars have their own planetary systems. It does seem likely that amongst the millions of stars, some may have planetary systems not unlike ours. The planets in the solar system move round the sun at different speeds The nearer planets move faster than the more distant ones

Stars vary in brightness Some are easily seen; others are just visible with the naked eye, while yet others can only be seen with telescopes The brightness of a star depends on its intrinsic brightness or the amount of light it radiates per unit surface area The brightest star in the heavens is Sirius But there are fainter stars which will look brighter if placed at the same distance from the earth as Sirius.

The light radiating from a star may be reddish, yellowish or bluish, depending on how hot the star is Spectroscopes are used to determine the colour of stars where the eye ceases to be reliable guide When the spectra of two or more stars are similar, the astronomer knows

TABLE 6.1

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
1 Distance from the sun (in million miles)	36.0	67 2	92 9	141 7	483 3	886	1782	2792	3671
2 Diameter (in miles)	3100	7700	7900	4216	88700	75100	32000	27600	3700
3 Volume (Earth=1)	0 06	0 92	1 00	0 15	1 312	734	64	42	0 1
4 Mass (Earth=1)	0 04	0 81	1 00	0 11	317	94,9	14 7	17 2	0 1
5 Surface temperature (in °C)	410°	120°	25°	0°	−138°	−153°	−185°	−200°	−211°

that their temperatures are also same The nature of the spectra does not depend on the distances of the stars. The stars, Vega and Sirius, show similar spectra and are at the same temperature though their distances from the earth are different Stars are classified in order of their temperature and colour There are orange or red stars, placed in Class M, with a temperature of about 3000°C. The orange stars of Class K have a temperature of 4000°C Stars of Class G, to which the sun belongs, have a pale yellow colour, with a temperature of 6000°C Yellow stars of Class F have a surface temperature of 7000°C. The A Class stars like Vega and Sirius are white and have a surface temperature of about 10,000°C.

The B Class stars are bluish white and lie in the range of nearly 20,000°C The hottest stars are in Class O, these look bluish and have a surface temperature of about 50,000°C.

Most of the stars of a certain type are roughly of the same size and emit the same amount of light. This is used to determine their relative distances

Variable stars

Two stars, when quite near each other, may not be identified as separate stars and appear as a single star They may be two stars revolving about one another. They are called 'binary stars' One star may pass in front of the other, causing the light from the twin stars to vary in brightness Such binary stars are fairly easy to identify and study

There are certain stars which cannot be classified in this general way. Some of them show variations from these general rules A group of stars, due to some internal occurrence, show fluctuations in their brightness This is a phenomenon which we still do not understand. These stars are divided into three classes: cepheids, long period variables and irregular variables Cepheids are giant stars, visible to the naked eye; their period of variation is from $1\frac{3}{4}$ to 50 days. Scientists think that they expand and contract rhythmically causing variation

in brightness and temperature Long period variables are red-coloured giant stars with low temperatures Their periods of variation of luminosity are not regular and vary from a 100 to about 600 days Irregular variables are giant stars with an irregular period

Novae

Another class of stars are called novae or temporary stars. These stars are generally too faint to be noticed, however, they suddenly become quite bright as if some sort of a giant explosion had taken place in the star They then start to diminish in intensity, becoming gradually fainter

The Galaxy

Stars are not uniformly distributed but they seem to move in certain regions of space rather than in others In fact, a system of a large number of stars of which our sun is one, seems to be whirling around in space in the form of a large extended disc. The Milky Way or Galaxy that we see in the sky as a whitish and irregular band is the view of the disc from our position within this galaxy Our galaxy is a flattened, disc-like system, which spins like a pin-wheel and has a dense accumulation of stars at the centre The spiral arms contain some bright and massive stars as well as clouds of gas and dust. We see the bright stars by noting them in relation to their position in the Milky Way. The Milky Way is a vast collection of nearly 150,000 million stars. The galaxy is so vast that light travelling with a velocity of 3×10^5 km/sec will take 10^5 years to cross the entire disc from one end to the other The distance of the sun from the galactic centre is 30,000 light years The sun moves round the galactic centre and takes nearly 250 million years to complete one orbit, this is called one cosmic year

Nebulae

Through a telescope we can see bodies similar to the one shown in Figure 6.5 They
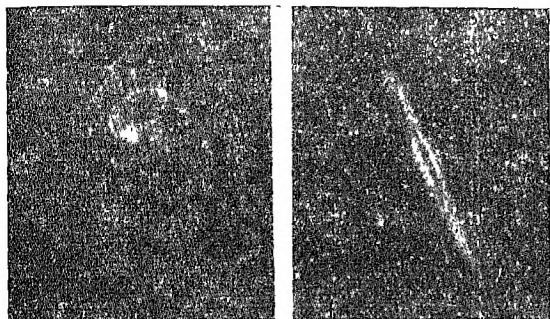
FIG 6 5 *Spiral nebulae*

are called spiral nebulae. They are galaxies other than our own and each one of them is composed of millions of stars Spiral nebulae also contain clouds and clusters of stars Some of the spiral nebulae are very well defined, with two spiralling arms; others may be somewhat diffuse The nebulae show various differences from one another Some may be ellipsoidal or spiral or even very open and irregular spirals They are of various sizes and structures There are also nebulae of irregular shape Occasionally, two or three spiral nebulae may be found close together

The spectral lines of hydrogen or other elements emitted from the spiral nebulae are observed to be shifted towards the longer wave lengths, i e , towards the red side of the spectrum. The shift is quite prominent It is explained by assuming that the nebulae are moving away at a high velocity from our galaxy. Since all the spiral nebulae show the red shift, one assumes that they are all running away from each other. This is the same as saying that the universe is expanding like a bubble of gas

Astronomy in everyday life

Astronomy is not only a fascinating subject today, it has been fascinating to our forefathers too, and will remain so, as long as civilization exists The early astronomers noticed that the

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relative positions of the stars remain fixed, although they all rise in the east and set in the west The moon, the planets and the sun, however, change their positions with respect to the background of the stars The regularity of the position of the sun and the moon amongst the stars became a method of reckoning time The time interval between successive sunrises is our day It is fairly constant, although it does undergo seasonal variations

Between one full moon (or new moon) to the next is another time interval which is also fairly constant, it is nearly 29 days (or almost a month). Our seasons are related to the position of the sun at noon, which is the maximum altitude of the sun In a very broad sense, there is a cyclic variation of climate, from cool to warm and back to cool, during a fairly definite period of time (the year) These well-defined periods of day and year are respectively related to the rotation of the earth on its axis and the revolution of the earth around the sun Since the stars are relatively fixed, the time interval between the consecutive transits of a star over the observer's meridian is called the sidereal day The consecutive transits of the sun define the solar day, which differs slightly from the length of the sidereal day, taking four minutes longer Since the length of the solar day varies from season to season, a mean solar day is also defined. The sidereal day is, however, more exact and is divided into smaller divisions such as hours, minutes and seconds The earth completes one revolution round the sun in one year or, rather, in nearly 365 25 sidereal days Although the sidereal day is not exactly constant, due to irregularities in the earth's rotational motion, it is still the basic unit as it remains almost constant over long time intervals. Scientists have developed very accurate clocks like the 'quartz clock' and the even more accurate 'atomic clocks' These are now related to the sidereal time However, since these clocks are very accurate, irregularities of the earth's motion (sidereal motion) can be detected and observed by comparing

sidereal time with the time kept by these accurate clocks

One of the important early uses of the study of the stars was the development of the calendar The solar calendar in common use is based on the motion of the earth around the sun, which takes about $365\frac{1}{4}$ days To enable us to work conveniently the year is made up of 365 days, except for every fourth year, the leap year, which is given 366 days This keeps the average year at a constant value of $365\frac{1}{4}$ days The Saura Saka calendar of our country and the Gregorian calendar now used all over Europe are examples of the solar calendar Lunar calendars are also in use, such as the Hizri and the Vikram calendars. However, as these are based on the lunar month they cannot remain in tune with the seasons Festivals based on the lunar calendar tend to change their place in the year and occur in different seasons

Another important use of astronomy from the earliest times to the present day is in navigation A given star, at a given time in a given place (that is, for a given observer), is in a fixed position in the sky relative to the horizon Conversely, if at any given time, the position of a given star is measured with respect to the horizon, an observer can locate his own position This is the basis for using stars in the navigation of ships, aeroplanes and even space craft